THE UNIVERSITY OF QUEENSLAND

Bachelor of Engineering Thesis

Evaluation of the Gas Drainage Efficiency at the Grasstree Mine

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ABSTRACT

Inappropriate coal mine gas management has the potential to cause catastrophic disasters resulting in multiple fatalities. Gas is naturally released into the mining work environment during production and development; pre- and post-drainage form the basis of gas management. The Grasstree Mine site located in the Bowen Basin is an underground coal mine that utilises both pre- and post-drainage techniques. Unique to Grasstree is the high gas content of the mining and adjacent seams. This project studies the methane capture efficiency of the GC906 longwall panel against critical events that affect the gas management and ventilation of the mine. The aim is to identify the most effective gas management techniques for future longwall blocks with reduced ventilation at the Grasstree Mine.

The data utilised in this project was post-drainage flows and concentrations provided from measurements and recordings taken for the full duration of GC906 mining. Methane capture efficiency was calculated for each hour for the duration of GC906 longwall mining; 18/11/2016-21/06/2017. The critical events analysed were:

- Initial longwall square-up period;
- Transitioning from two to three return gateroads;
- Full duration of a HGH well transitioning from long to short goaf gas drainage;
- The restriction of a return roadway to improve goaf dynamics; and
- Analysis of the effects of vertical post-drainage holes over the maingate side on the overall gas drainage.

Analysis of the longwall square-up period provided the insight that the methane capture efficiency was unstable and averaged 71% (average for the GC906 duration was 90%). This low efficiency will strain a reduced ventilation system due to gas dilution requirements. Improvements to the UIS goaf drainage HGH methods are required. Although, there were two in-seam post–drainage wells (9CT ad 17CT) for the GC906 panel. This will allow more gas extraction during maintenance periods of other post-drainage techniques.

Extending the scope of this project to include capture efficiency of other major mining gasses would be beneficial for understanding how gas management differs with gas compositions. Determining the pre-drainage extraction efficiency will determine where improvements can be made prior to mining the longwall panel. This will affect post–drainage gas management.

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1 INTRODUCTION

1.1 BACKGROUND

Gas management is a fundamental part of underground coal mining, specifically in longwall method mining. Gas management is the technique of managing gas levels and ventilation in development and longwall panels before and after production. Aziz, Black, and Ren (2011) stated that ineffective control and management of coal seam gas increases the risk of creating conditions that may result in either a coal and gas outburst or a methane and coal dust explosion. This poor management may lead to general gas bodies within areas of the mine exceeding statutory limits.

Successful gas management is achieved by draining in–seam gas to reduce in-situ content to below the threshold limit values (TLV). This is done by adequately diluting non-captured gas with ventilation (Aziz, Black and Ren, 2011; Gillies and Wu, 2013). Gas drainage may occur via surface or underground methods. Surface drilling patterns extend the length of longwall panels with boreholes extending to the working seam. Underground drainage involves pre-drainage of development headings, across panel drilling, and cross measure drilling to the adjacent seams (Dunn and Alehossein, 2002). Pre-drainage occurs before development or longwall operation has commenced, and is performed to prevent gas outbursts and irrespirable atmospheres while mining. Post-drainage allows relief of gas in goaf areas. This drainage allows the atmosphere in active and sealed goaf areas to remain at a non-explosive level of seam gas (Hayes, 1982; Thakur and Dahl, 1982).

Gas drainage is important within the underground coal industry because of the increased safety standards and worker interaction in development and production areas. The evaluation of gas drainage efficiency at the Grasstree Coal Mine is the aim of this research project. Production of the German Creek seam began operations in 1988 in the Bowen Basin mining area by Southern Colliery, which – purchased in 2004 – now operates as Capcoal's Grasstree. Both pre-and post-gas drainage methods are utilised in this underground longwall mine. Currently, five longwall blocks (GC – German Creek Longwall Seams) have been extracted in the 900 panel series; operations are extracting GC906 with future mining planned to extract up to GC910. A previous proposal of changing the longwall operation from three to two heading maingate – resulting in a single heading return – has been approved for GC908 onwards and will commence in Quarter 1 2018. With reduced ventilation available for gas dilution, gas management techniques will be heavily relied on. The motivation for Anglo American to conduct this project is to evaluate their current gas drainage effectiveness and to implement the best method(s) for future blocks, using the single heading tailgate and reduced ventilation.

1.2 Aims and Objectives

The aim of this research project is to identify the most effective gas management techniques for future longwall blocks at the Grasstree Mine. This will be achieved by completing the following objectives:

- Gain a comprehensive understanding of gas management systems in the underground coal industry;
- Determine performance characteristics for the evaluation of each gas drainage management technique;
    - Determined by Ventilation Compliance Superintendent by week beginning 22nd of May, 2017;
- Analyse data from the GC906 from site upload;
- Examine the performance of the current gas drainage techniques used at the Grasstree Mine;
- Identify scenarios where during the GC906 extraction drainage may have been effected and examine performance;
- Establish a comparison study between the high performing gas management strategies during the scenarios to identify the most effective gas management technique; and
- Provide recommendations as to which gas drainage methods are to be included for future longwall panels as well as future research.

1.3 Scope

The scope of this research project has been minimised; keeping unnecessary objectives out of scope enables analysis to be focused on the direct objectives and aim. Table 1 presents the factors being kept out of scope for this research project.

Table 1:
Scope of project

Factor	Influence
Collection of gas drainage data from the Grasstree Mine site	The data will be provided as per an arrangement made between the author and the Anglo American Metallurgical Coal Supervisor for the project
Ventilation simulations of the Grasstree Mine	The simulations have fixed values because of the proposal for future mining at Grasstree Mine and cannot be changed for the purpose of this research project
	The ventilation has a fixed value of $50m^3/s$ as proposed by the supervisors on this research project
	All simulations and site models are available on site records and can be accessed via the database created for this project
The proposed mine layout for the future development of longwall blocks	This thesis will not change the proposed layout of the impending longwall blocks
	All proposed layouts and changes made will be done so at the discretion of mine site personnel
Gas capture efficiency will only be analysed for methane gas	Recommendations have been made to allow for future study into capture efficiencies of other major mining gasses

The above points explain the factors that will be left out of scope for the foreseeable future of this research project; but, this may be amended due to changes provided by involved supervisors. After discussions with supervisors, it was also decided that aspects such as gas pumping influences, cost of new infrastructure, and the management of the ongoing project will not be included in this thesis.

1.4 METHODOLOGY

The methodology of this research project will follow the outlined objectives so to achieve the overall aim of identifying the most effective gas management technique. Table 2 features the methodologies involved with completing each of the objectives.

Table 2:

Project methodology

Objective	***Methodology***
Gain a comprehensive understanding of gas management systems in the underground coal industry	Complete a review of previous studies reported in literature
Determine performance characteristics for the evaluation of each gas drainage management technique	Review previous studies where gas management and gas drainage are key factors in the research field Review the drainage KPIs
Analyse data from the GC906 from site upload	Revise data to ensure inconsistencies are identified and rectified before continuing the analysis process Ensure all data is in the correct units (L/s) to maintain consistency
Examine the performance of the current gas drainage techniques	Calculate the extraction, vacuum, and blower make Calculate the methane capture efficiency of the gas drainage system for longwall panel GC906
Identify scenarios where during the GC906 extraction drainage may have been effected	Scenarios discussed with Ventilation Compliance Superintendent w.b 22/05/2017 Identify when each scenario occurred and examine the performance of each gas drainage method
Establish a comparison study between the high performing gas management strategies during the scenarios	Identify relative comparisons and examine the alterations to performance of gas drainage methods
Provide recommendations	Make conclusions for each scenario and establish which gas drainage methods require improvement or further analysis for an effective gas drainage plan

1.5 SIGNIFICANCE

This thesis is significant to the Queensland coal industry, the Grasstree mine site, and all persons involved. The topic of this thesis is significant because of the Queensland coal mining industry’s current focus on safety; in particular safe gas management practices. The significance for the underground coal mining industry is that the research will help to combat the safety stigma involved in gas management; especially at a site where seam gas is at such a high level.

The significance of this project to Anglo American Metallurgical Coal and The University of Queensland is that it creates another strong link between the university and industry through research work (allowing an undergraduate student the opportunity to undertake a research project for a pending gas drainage improvement within an underground coal mine). Because of an arising issue at the Grasstree Mine site, the success of this project is important for future production. This research project will provide a strong recommendation for the most effective gas management technique available for future mining, at the Grasstree Mine.

This undergraduate thesis provides the author with exposure to the Queensland underground coal industry. Giving recommendations for safety, operations, and technical services in an operating coal mine and being part of a solution to a real problem is fundamental to the learning objectives of the study, which the author holds in high regard.

2 COAL MINING

2.1 LONGWALL MINING

Coal mining is a primary industry in Australia, with the majority of underground mines featuring longwall mining methods. Longwall mining consists of development and production faces. The development is the bord-and-pillar sequence, which is used for the main headings and gate roads around each longwall block. The production occurs by longwall mining the coal within this block in a retreating fashion towards the main headings. As the longwall shearer cuts coal along the width of the face and advances protected by roof supports leaving the roof behind the supports to cave (Coughlan, 2015). While production advances, development must continue to allow future production to start in the next longwall panel. This relationship is illustrated in Figure 1.

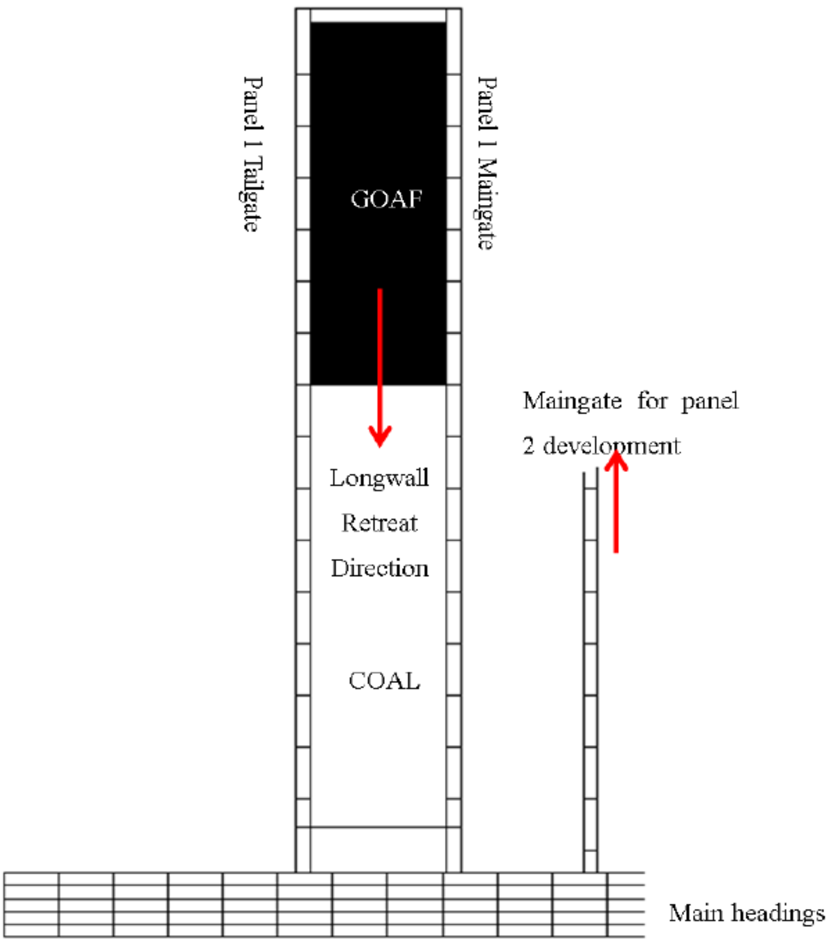

Figure 1: Longwall mining production and development sequence (Coughlan, 2015)

The development for each longwall panel must be complete before production can commence. This includes adequate ventilation from the maingate to dilute gases formed in the working area. Headings in the return roadways, geotechnical events, and restrictions all make gas drainage and ventilation a challenging and dynamic tasks. Longwall mining increases the gas release as well as accumulation of gases in the goaf areas. The ventilation system of a longwall panel typically utilises the maingate airflow to dilute gas at the cutting face, this airflow travels through the tailgate and into the return roadways as illustrated in Figure 2.

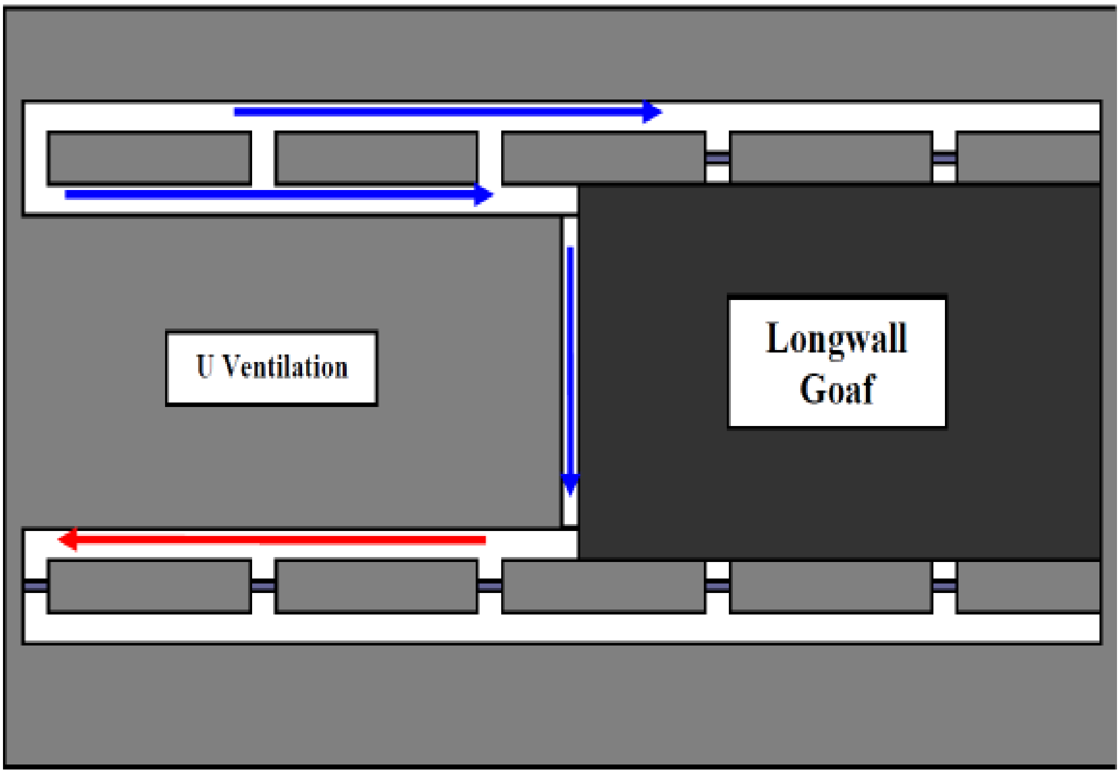

Figure 2: U-Ventilation for longwall panels (Balusu and Humphries, 2007)

This style of ventilation transports diluted air away from the majority of the work personnel in the mine, and provides an acceptable work environment throughout the longwall panel.

2.2 Gases

Gas in coal seams has been a problem since the early extraction of coal (Durham Coal, 2010). Seam gas usually consists of several naturally occurring gasses. The major of these include methane (CH_4), and carbon dioxide ($C0_2$). In its virgin state, the gas is absorbed by the coal. When the pressure surrounding the coal is lowered, through mining of the seam, the gas will flow steadily through micro-cracks into the mine workings (Ogilvie, 1995). The methane contained in the mine gas is of a very high level. In most cases, virgin seam gas may have a 70% methane content. Although the explosive range of methane is between 5% – 15% with the presence of oxygen (0_2), any inappropriate dilution of the virgin seam gas may lower the methane content, risking an explosive mine atmosphere (Aluko, 2001). Methane is an asphyxiant, and, therefore, replaces oxygen within a working environment; this causes a drop in oxygen levels. Gas within a coal seam also poses a risk of outbursts. These outbursts occur spontaneously. But studies have determined that outbursts may be triggered due to high gas levels in a particular area of the seam surrounded by weakened rock caused by mining of the seam (Choi and Wold, 2001). Other triggers include airblasts, shot firing (of dyke material), and explosions, as Choi and Wold (2001) further explained. Gas present in the goaf occurs because of the longwall mining method where gas is released upon the mining of the coal seam. The gas within the goaf area builds up until the longwall block is depleted. The goaf is then sealed to prevent gas leaking into the remaining mine workings. Normally, this gas is methane rich, which allows the goaf to stay out of the explosive atmosphere range.

Early detection of mine gas has been used since the early 19th century. As Noack (1998) explains, early detection of firedamp (methane) was used in German bord-and-pillar mines. Canaries, which normally sing until exposed to trace levels, would signal coal workers to evacuate the mine. Before the use of electronic gas detectors, a chemically infused paper was taken into coal mines. The paper would turn brown upon exposure to carbon monoxide (usually present after an explosion/fire). Between 1980 and 1985 electronic gas detectors were made abundant, which allowed the early detection of mine gases. This also allowed rating systems to be brought into the mining industry for operation slowdowns, shut downs, and personnel evacuations, when certain mine gas levels were present. There are two historical ways to control the amount of gas in a mine: first to dilute the gas via ventilation methods, and second to capture seam gas and extract to a safe location (usually the gas plant on the surface).

2.3 MINE ENVIRONMENT

Coal mining has a stringent safety standard because of the large amount of fatalities which have occurred in the industry's past. Underground coal mining has a higher standard because of the high consequence, principal hazards while operating in all areas of the mine. Principal hazards include (Coal Mine Safety and Health Act, 1999):

- Ground or strata failure;
- Inrush of any substance (usually water hazards);
- Mine shafts and winding systems;
- Air quality, dust or other airborne contaminants;
- Spontaneous combustion;
- Subsidence; and
- Gas outbursts

The aforementioned hazards are controlled differently within all underground coal mines. In Australian black coal mines, Bartosiewicz and Hargraves (1997) stated that ‘the gas content of some coal seams can be as much as $50m^3/t$, the average being $10\text{-}15m^3/t$ depending on gas type and therefore are classified as gassy seams’. Gas outbursts and air quality are both controlled using prescribed and practiced gas drainage techniques. Gas outbursts take place when an irregularity within the seam interferes with the usual release of gas. This can happen during pre-drainage, operation, or post-drainage. Gas outbursts within the mine environment may cause serious consequences if proper controls are not in place. Gas content of new workings must be evaluated to understand the amount of gas within the working and the consistency at which the gas will flow.

Air quality and contaminates may be controlled using proper gas drainage strategies and ventilation engineering controls. Air quality refers to the amount of contaminants in the ventilation system; contaminants include to dust, diesel particulates, and gases. Ventilation is used primarily to ventilate the mine to create a safe work environment for all underground personnel. Through ventilating, air quality is increased due to the removal of heat, gases, and other contaminates. Dilution of gases is required by legislation and is a fundamental practice to ensure all underground operation crews work without respiratory harm.

Monitoring of methane levels ensures alarms, shut downs, and evacuation can follow the prescribed trigger, action, response plans (TARPs). Monitoring systems present in an underground coal mine include stations, vehicle and machine alarms, and personal monitors that are carried by statutory personnel or as required. Monitoring allows the safe registration of hazardous areas and changing mine environments.

3 GAS DRAINAGE IN COAL MINES

3.1 OVERVIEW

Gas drainage is an integral stage in the underground coal spectrum. As part of the underground ventilation, gas drainage provides means of extracting seam gas from the mine to prevent outburst and possible risks of methane explosions. As described by Hargraves (2004), early gas drainage work in Australian coal mines was aimed at removing gas prior to mining to reduce the use of dilution by means of mine ventilation. By removing the amount of dilution required by the mine ventilation, more air may be provided to other heated areas of the mine. Historical gas drainage methods are still, to an extent, presently used in the mining industry. The use of boreholes to extract mine gas is still utilised in all Australian underground mines; however, with the advancement of pumps and drilling these boreholes have become more efficient gas drainage methods. As previously stated by Ogilvie (2001), when the coal seam is lowered in pressure – due to mining operations – the gas will flow through the micro-cracks or structures in the seam. But, with the use of borehole drilling, the gas may be captured by drilling into the seam, relieving the pressure and allowing the gas to flow into the created borehole. This allows the gas to be led into the pipe range and extracted out of the mine.

Lunarzewski (2001) presented a conference paper at the Coal Operator's Geotechnology Colloquium that outlined the current gas drainage practices within the underground coal industry at the time of publication. This paper provides a detailed outline of the increasing gas issues in gassy mines and how the effectiveness of the methods can affect the production of the mine. The paper explains the uses of pre-drainage and post-drainage and explains the historical uses of these drainage methods. Lunarzewski (2001) explains that pre-drainage is a term given to the drainage of the mining or adjacent coal seam/s prior to mining in the area. This gas is extracted through the pipe ranges in place and pulled to the surface through the use of vacuum pumps. Pre-drainage occurs via underground and surface boreholes. Post-drainage is the capture of gas from the roof and floor locations after mining has commenced. This allows the gas to be released from the surrounding areas because of the reduced pressure in the seam after mining. Post-drainage methods require boreholes to be drilled either vertically from the surface or horizontally in the mine using Horizontal Goaf Holes (HGH) methods.

Post-drainage of goaf regions occurs through vertical boreholes into a sealed goaf area. Live goaf drainage is not appropriate due to equipment and personnel still being in the longwall area. Goaf drainage in an underground mine is crucial as these large amounts of gas fluctuate because of barometric pressures, as described by McInerney, and Brown (2015).

3.2 DRAINAGE METHODS

3.2.1 Surface to In-Seam Drainage

Gas drainage systems use boreholes to coal seams to extract seam gas. The boreholes are broken into two categories: surface to in-seam drainage and underground in-seam drainage. Surface to In-Seam (SIS) drilling practices are commonly utilised in Australian gas drainage methods. SIS drainage requires the use of boreholes from the surface of the mining lease to the coal seam where gas extraction is required, illustrated in Figure 3. Thomson and Qzn (2009) state that gas drainage was commonly carried out by rotary drilling methods – with mixed success – during the 1980's to early 1990's. The mixed success highlights the issues that arise when drilling deep holes via a rotary shaft. Holes being drilled at large depths will divert away from the vertical guideline due to varying rock strengths and other geological features (dykes, etc). Traditional longwall gas drainage methods utilise SIS drilling for both pre- and post–drainage. Pre–drainage SIS holes are required for gas extraction with an extended lead time before operations commence. Post–drainage SIS holes are used for goaf gas drainage, these vary from pre–drainage wells as a larger size and longer spacing is required.

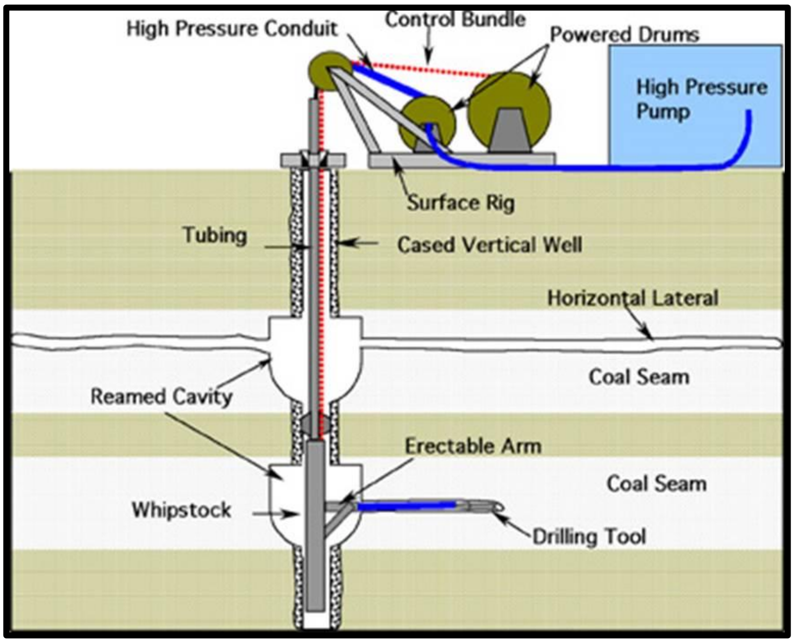

Figure 3: SIS drilling illustration (Kizil, 2017)

Two common methods of SIS drilling implemented in Australia are Medium Radius Drilling (MRD) and Tight Radius Drilling (TRD). MRD is a typical drilling method for drainage wells for medium depth seams. This method allows a wider spread of the boreholes due to the larger radius of curvature, see Figure 4. MRD is favoured within the Bowen Basin coalfields due to its independence from underground workings, lower cost, and it reduces the need of cross-panel UIS drilling. However, the MRD systems require a significant lead time, between 18 months to 3 years to allow water draw down. This long lead time requires wider spacing of the boreholes to become cost and time effective (Gou *et* al, 2011).

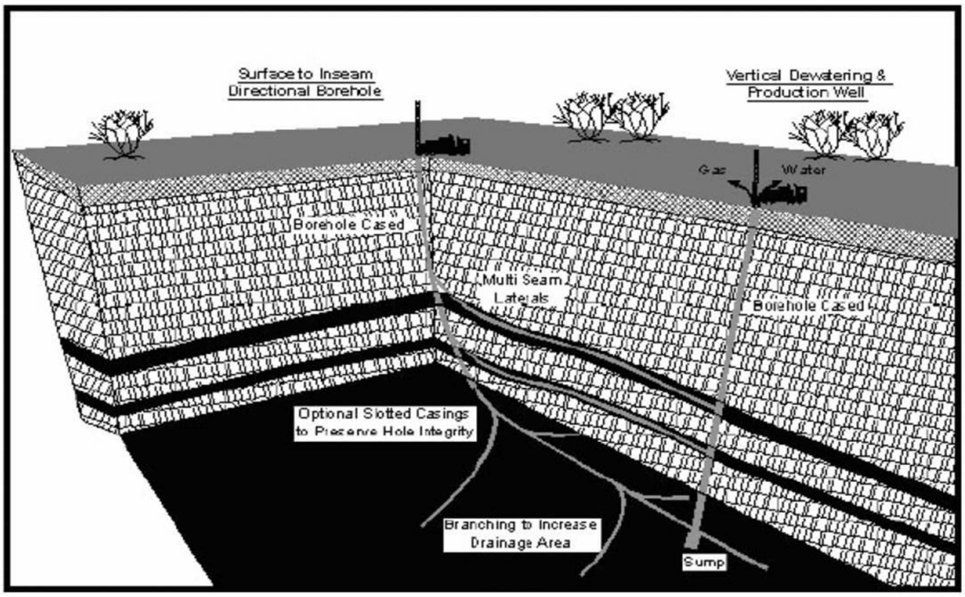

Figure 4: MRD drilling process (Kizil, 2017)

Tight Radius Drilling was derived from the MRD practice for sites that have less surface area available but significant gas content that must be drained prior to mining. This method of pre-drainage utilises a coil string wound onto a large drum rather, than drill rods. TRD allows closer spacing of pre-drainage holes, due to the smaller diameter.

Deviated drilling is explained by Balusu *et* al. (2006), a borehole is drilled at an angle to penetrate the coal seam and guide through layers of strong rock, enabling a larger area of pressure release to extract larger amounts of seam gas as seen in Figure 5. This methods was first used in American coal fields to bulk extract gas in medium – thin seams.

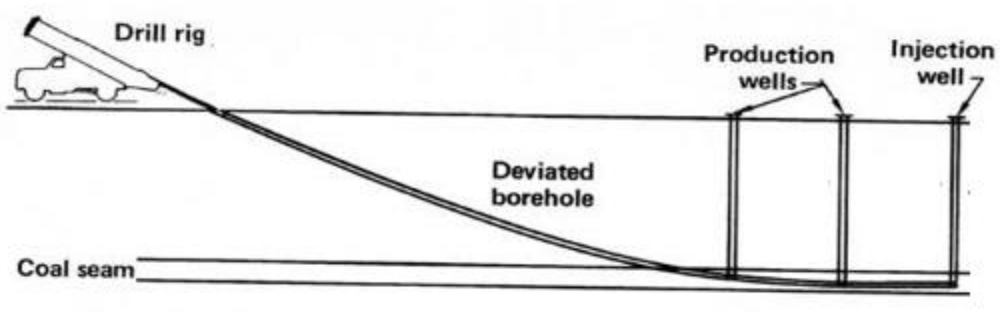

Figure 5: Deviated borehole drilling illustration (Balusu *et* al, 2006)

MRD practices are used at the Grasstree Mine, because of the available surface lease area above the longwall panels, as well as the cost effectiveness and larger gas extraction requirements.

3.2.2 Underground In-Seam Drainage

Underground drainage grew in popularity in the early 1960s where surface drainage was limited by depth and boreholes reached lease boundaries (GE Mining, 2003). Underground drainage was explained by Lunarzewski (2001) as horizontal drainage wells that are utilised for pre–drainage of longwall and development areas to allow increased mining productions and minimising the risk of gas outbursts. An example of a simple gas drainage pattern is illustrated in Figure 6.

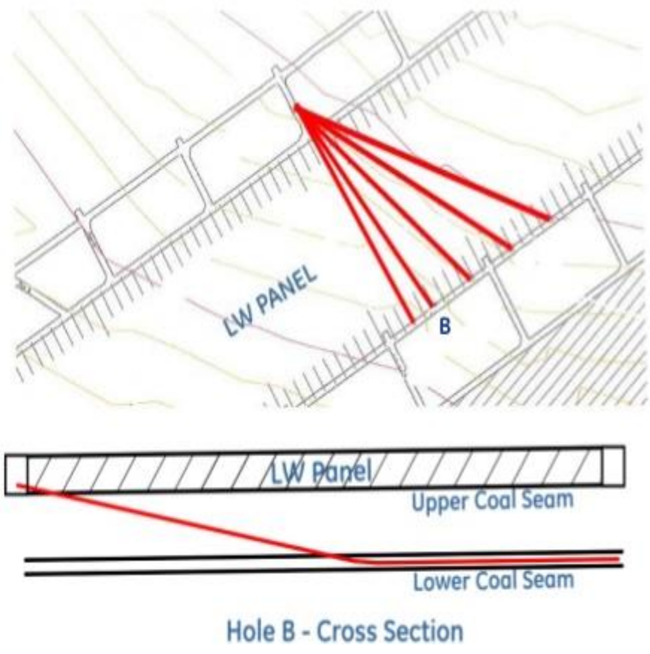

Figure 6: Simple pre–drainage pattern (Lunarzewski, 2001)

The number of boreholes required for UIS drainage patterns depend on the amount of gas to be extracted and the time allowed for pre–drainage. The holes are drilled with the use of an underground drill rig, and are usually driven by an experienced driller and loaded by an 'off-sider'. Hole can be drilled into adjacent seams above and below the mining seam and active goaf areas. Each hole can have a number of branches that are used to extend the drainage area. These are guided through the practice of roof and floor to follow the coal seam as it fluctuates in height, as seen in Figure 7.

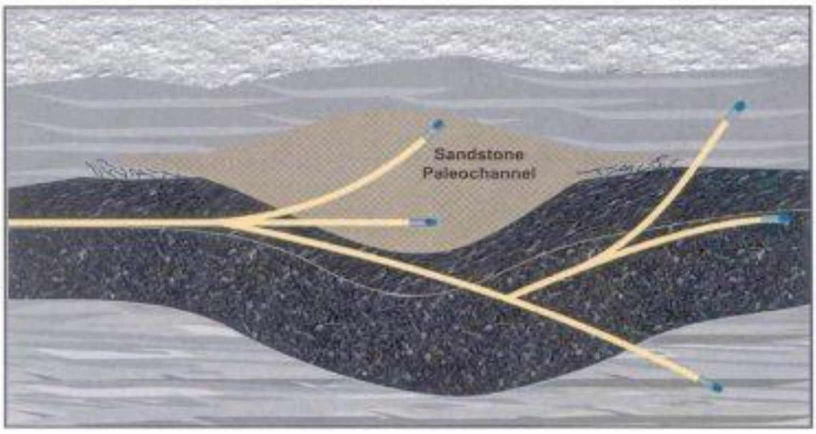

Figure 7: Roof and floor touches (FHA, 2015)

UIS drilling are used for drainage of both the mining seam and adjacent seams. At the Grasstree Mine UIS drilling extracts gas from three adjacent seams; Corvus 1 and 2 are located above the mining seam while the Lower German Creek is located below. These seams are pre–drained due to the close proximity to the mining seam, are relieved of pressure from extracting the longwall coal, and must be drained to ensure outburst risk is minimised (McInerney, and Brown, 2015).

3.2.3 Goaf Gas Drainage

Goaf gas is an accumulation of tainted gas ejected from the mining of a longwall face. The gas is pushed behind the longwall supports into the goaf area. The goaf area is hazardous because the longwall mining method requires the untimed collapse of the roof behind the chocks. If the roof is particularly strong or does not collapse for some time, a larger roof collapse may occur, which will push this gas into the working area at the longwall face, tailgate, and maingate roadways. This air blast can cause major injuries or fatalities depending on size; or, more severely, can create a chance to ignite the explosive mixture of gas from heat streaks, which are common at the longwall face, and cause a gas explosion to propagate throughout the mine and cause fatalities.

Goaf gas drainage is a method of post–drainage. It involves drilling large diameter boreholes vertically from the surface to the goaf area. Once the longwall face has passed the planned borehole, the hole is cased and begins extracting the gas to eliminate the build-up and propensity for a gas explosion. Typically, methane is the primary gas to remove, however, all impurities should be extracted. Figure 8 illustrates the goaf drainage holes and the extraction of goaf gas.

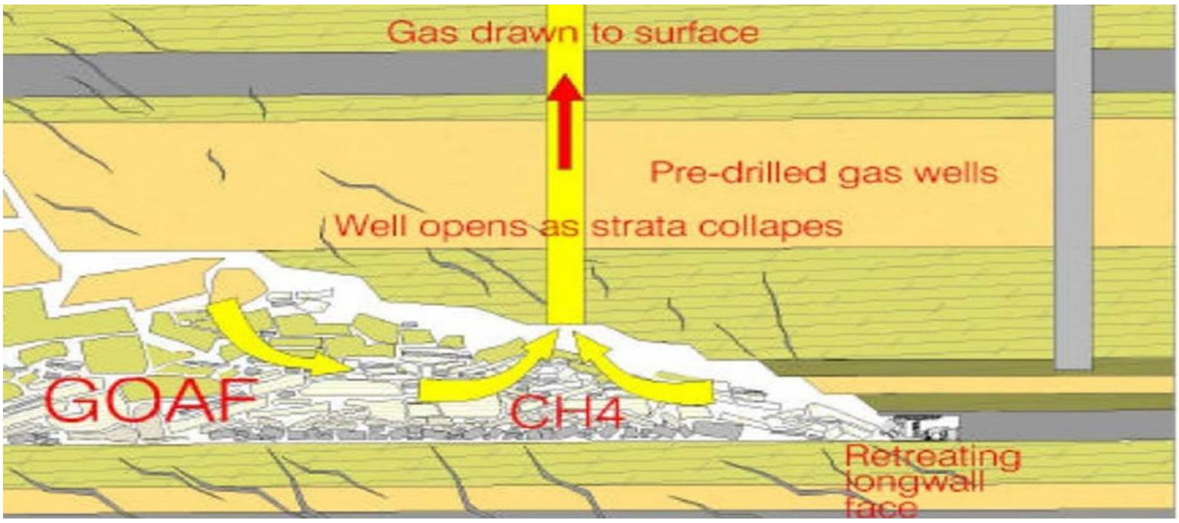

Figure 8: Goaf gas drainage (Gou *et* al, 2011)

Typical SIS goaf drainage boreholes range from 250–400mm in diameter. This depends on the gas extraction required, which depends on the gas content and ventilation requirements of the mining seam. The boreholes are spaced 100–400m apart and anywhere between 30–80m in from either gate road due to cavability of the goaf area and gas content (Gou *et* al, 2011).

Goaf gas can also be extracted using HGH methods at a post–draining stage. These holes are drilled in niches along the tailgate roadway to allow better access to the goaf area (Gou *et* al, 2011). These boreholes may be greater than 700m in length to extract early goaf gas accumulation. HGH boreholes are drilled using the same system as UIS pre–drainage holes, with water and gas pumps connected to a standpipe for the extraction of gas to the surface.

Goaf drainage removes the gas contents of an active goaf area. This method can also be used for maintaining the gas levels within a sealed off goaf, once longwall mining has been completed. Goaf drainage for a sealed goaf is commonly known as ‘adjacent goaf drainage’. The gas levels within a sealed goaf indicate the type of gases, explosibility limits, and mine

TARPs. Goaf holes should have a low oxygen ingress to prevent the propensity of spontaneous combustion within an active or sealed goaf (Gou *et* al, 2011).

3.3 GAS CAPTURE

3.3.1 Captured Gas

All gas pumped from within the mine using post–drainage methods flows through the vacuum plant. The vacuum plant is simply a mechanism that has the capacity to withdraw gas from the seam via overland pipelines and hold the gas for use or transportation. The use of overland pipelines provides simple transportation of high flows of gas at high pressure. Gas ranges for post-drainage using vertical wells or HGH methods are fed directly into the overland pipelines. This allows an instant gas release once boreholes are reamed, cased, and put online. These pipelines may join to larger pipelines depending on gas drainage quantity, range of the mining lease, and distance of the pipelines (Wang *et al,* 2016). Figure 9 shows the flow of gas from goaf post–drainage surface wells to the gas plant and blower flares. A split between the gas plant and blower flares is used to maintain ideal gas capacity at the gas plant for power generation.

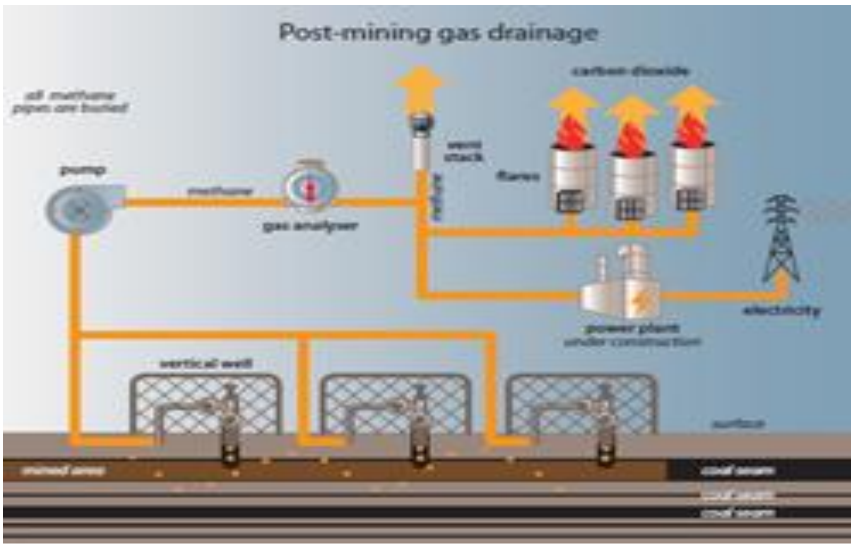

Figure 9: Gas flow for post – drainage (Glencore, 2017)

Some mine sites reuse this methane rich mine gas to convert to electrical energy to power the site’s substation. This provides a cheaper source of energy and the possibility to run the mine wholly or partially off the grid. Also, by not releasing the drained methane gas throughout the mining process greenhouse emissions are decreased, leaving a smaller carbon footprint.

Blower flares are used on mine sites where heavy gas drainage is required due to a high gas content within the mining seam. The captured gas that is unsuitable for power generation is burnt off via the use of several incinerators (Wang *et al*, 2016). The blowers combust the captured gas from the gas drainage processes and burn off at a central location on the site. There may be several flares present on site. However, the quantity of the captured gas determines how many flares are burning for any period of time.

Flaring methane to produce carbon dioxide and water vapour reduces the methane greenhouse gas impacts by 21 times (Glencore, 2017). Burning off the captured gas may be an issue within the surrounding communities. This method should be used sparingly, when costs for excess gas transportation outweighs the profit to be made from selling the excess gas.

3.3.2 Efficiency

Key Performance Indicators (KPIs) are examined for the thesis project to ensure the correct gas drainage methods. The KPIs depend on the overall aim of the project, which is to determine the optimal gas drainage method/s to be implemented for future longwall blocks at the Grasstree coal mine. A recent study conducted at the China University of Mining and Technology examined the gas emission of a coal mine. This was carried out by examining total gas content approximation, gas trends with increased mining depth, gas drainage method effectiveness, and gas capture efficiency (Wang *et al*, 2016); some of these key performance indicators are objectives for this thesis. This study was centred around Chinese coal mines; but, the basis of the examination provides a guide on how the gas capture efficiency may be obtained.

McPherson (1993) explained that the capture efficiency is simply the percentage of gas extracted divided by the total gas in the seam (the captured gas and that diluted by the ventilation system). With limited ventilation and increased gas for GC908 and onwards, there is a requirement to use the most efficient gas drainage methods, and therefore those with the highest capture efficiency. McPherson (1993) presents a simple equation to approximate the gas capture efficiency based on the ratio between captured gas and that left for dilution, see Equation 1.

$$Gas\ Capture\ Efficiency = \frac{Gas\ Captured\ by\ Drainage\ System}{Gas\ Catpured + Gas\ in\ Ventilation\ System} \times 100\% \tag{1}$$

Noack (1998) explains the use of advanced calculations for determining the amount of gas to be extracted from each borehole by gauging depth, flow, and expected gas rates. These calculations are not required because of the limited scope. However, these create a basis for understanding the complex relationship between coal permeability and borehole depth.

4 GRASSTREE MINE

4.1 PROJECT CONTEXT

This thesis is evaluating the gas drainage practices used at the Grasstree mine to identify which technique/s are the most efficient for GC908 and onwards, see Figure 10, Appendix A – Site Plan contains the Grasstree Mine Plan up to May, 2017 workings. The project assumes that there is limited ventilation of approximately 50m^3/s planned for GC908 and onwards. Research into the gas drainage project was conducted based on the impending longwall blocks and pre-drainage requirements for the foreseeable future of the mine. The gas drainage methods to be used per section of longwall must be evaluated and updated if required. In terms of research context, the project was given to the author by the Ventilation Compliance Superintendent at Grasstree as a potential thesis project due to the interest of the author in the field of ventilation and gas drainage within underground coal.

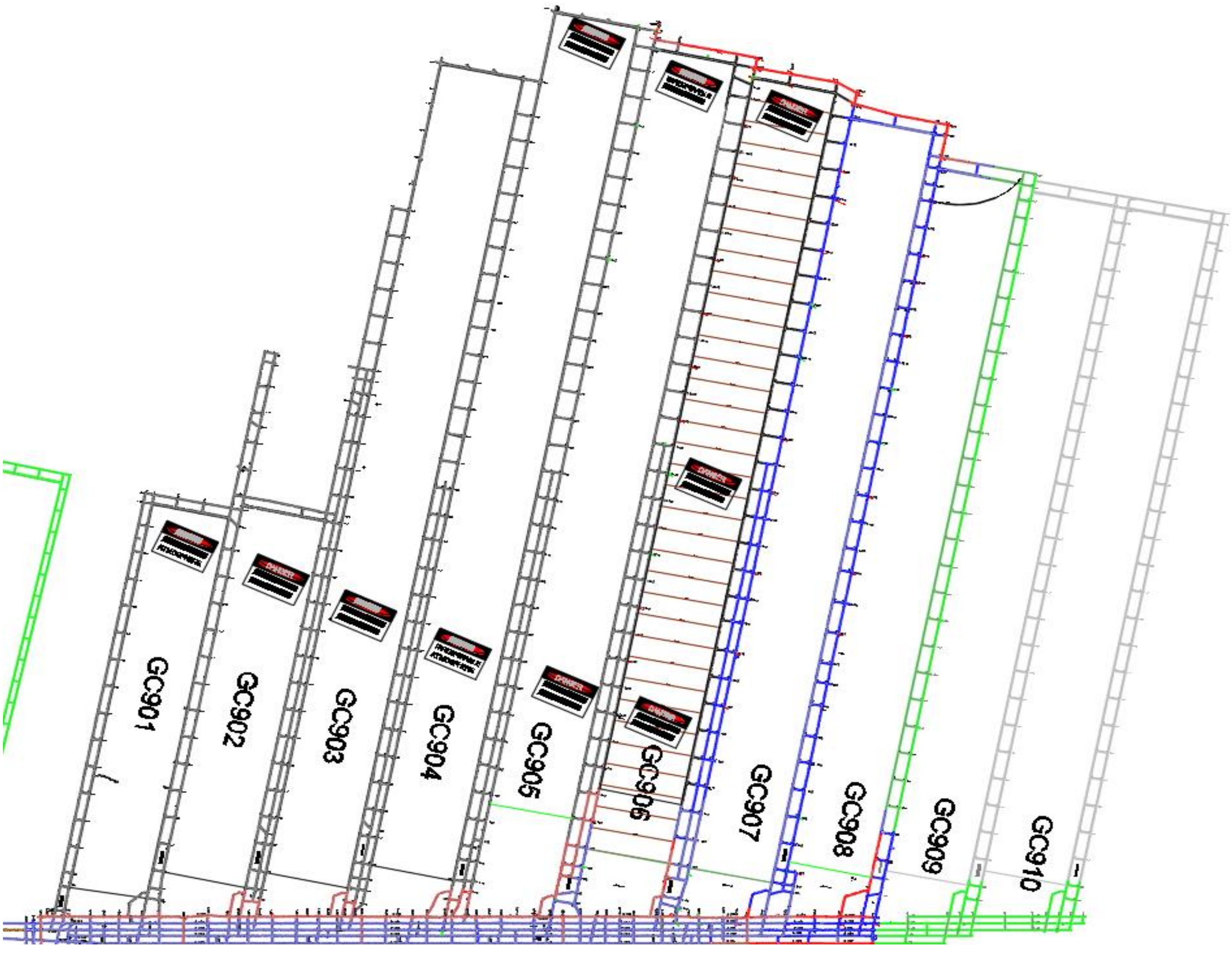

Figure 10: Layout of 900 Series Longwall Blocks at the Grasstree Mine
(Anglo American Metallurgical Coal, 2017)

4.2 GAS DRAINAGE PRACTICES

An extensive range of gas drainage techniques are currently practiced at the Grasstree Mine site. Due to the overwhelming amount of gas within the German Creek seam, these methods must be efficient to maintain a safe working environment at the site. Table 3 presents the gas drainage methods used throughout the 900 series panels.

Table 3:
Gas drainage scope

Gas Drainage Method	***Drilling Method***	***Drainage Type***
German Creek (mining seam)	SIS and UIS	Pre-Drainage
Corvus 1 and 2 Holes (overlying seams)	UIS	Pre and Post-Drainage
German Creek Lower Holes (underlying seams)	UIS	Pre and Post-Drainage
Tailgate Holes (Active Goaf)	SIS and UIS	Goaf Drainage
Maingate Holes (Active Goaf)	SIS	Goaf Drainage
Adjacent Goaf Drainage (Sealed Goaf)	SIS	Goaf Drainage

The utilisation of the UIS and SIS pre–drainage techniques are of great benefit because of the high gas content within the mining seam. Research of the gas drainage background and recent history of the methods used over the course of the mine life was completed. By identifying the history of the gas drainage methods used at Grasstree, the control, use, and impacts of utilising the current gas drainage techniques become clear.

The gas drainage efficiency is a major KPI for the improvement of gas management and ventilation techniques. The capture efficiency of the gas drainage system is the amount of gas extracted out of the mine and the amount much gas is left to be diluted by the ventilation system. By monitoring the efficiency, the mine can detect changes throughout crucial stages in development and production. The calculation by McPherson (1993) requires the data ranges for all gas drainage methods: SIS post – drainage from the tailgate and maingate sides, and UIS post–drainage as direct flows for each borehole for the duration of the GC906 longwall panel extraction. Vacuum plant and blower data includes the gas flow and concentration per hour, this is required to calculate the captured methane. The remaining methane is that which is left in the ventilation system, which for GC906 longwall is recorded through statutory ventilation checks in 906 panel dogleg as located in Figure 11.

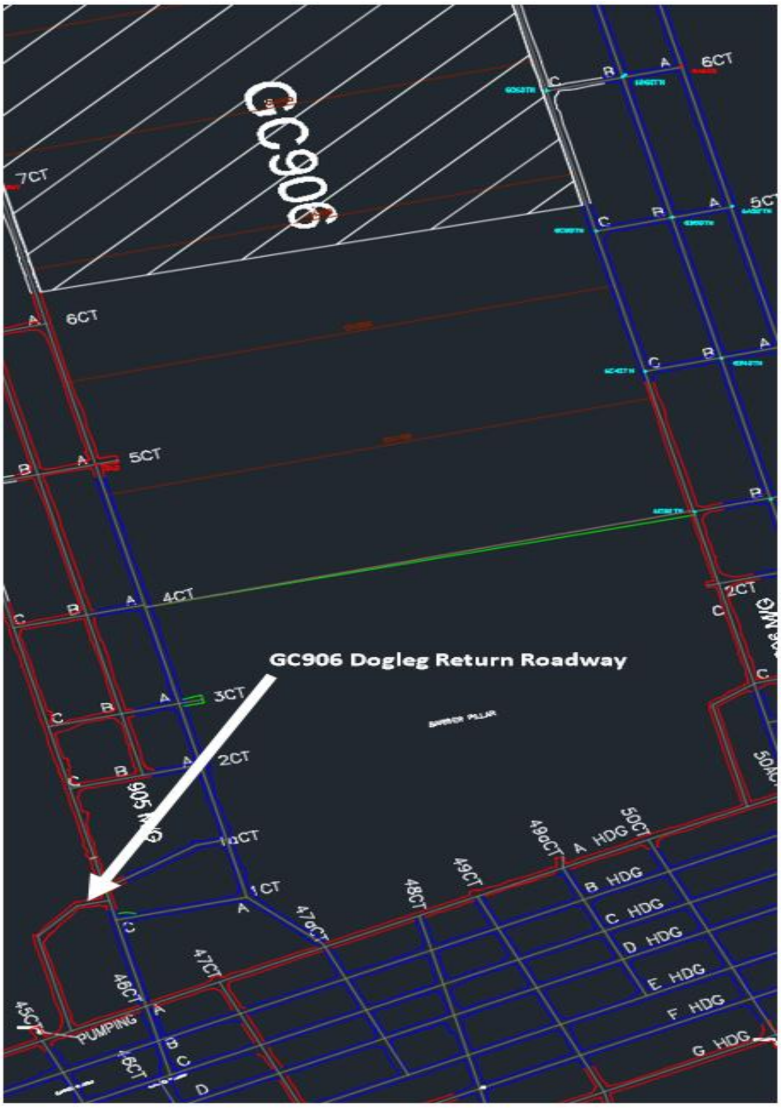

Figure 11: GC906 dogleg return airway (Anglo American Metallurgical Coal, 2017)

4.3 DATA COLLECTION AND ANALYSIS

4.3.1 Gas Drainage Data

SIS goaf drainage flows from the maingate and tailgate sides of the active GC906 goaf were provided, vacuum plant, blower, and statutory reports detailing the gas content for the GC906 panel were also provided. The data was shared via ‘Drop Box’ between the industry supervisor and the author, which meant minimal time lost between the literature review stage and the data collection stage this enabled the author to meet the set timeline and was deadline requirements for this project. All data put into a database where all flows from tailgate, maingate, and HGH wells were placed against a timeline for the 906GC longwall panel 18/11/2016 0:00 to 21/06/2017 15:00.

4.3.2 Maingate Drainage

The maingate data provided was the individual borehole flows for the duration of the GC906 panel extraction. This data ranged from 22/02/2017 0:00 through to 21/06/2017 15:00 with data sources for 15 maingate boreholes. Maingate boreholes were approximately 15” in diameter and spaced 150–200m apart. The boreholes utilised trailer equipment with flow recorders to measure the gas flow through the hole. Gas flowed from the SIS holes through overland pipe ranges to the vacuum plant. The data was shared via the ‘Drop Box’ as individual Comma Separated Value (.csv) files for each borehole. Each .csv for maingate holes was named according to the corresponding hole number; for example, maingate borehole 1 was named, 906MG-01. Each .csv file contained data for the borehole, including:

- Log time: date for the borehole gas extraction given per hour;
- Well information: site, location, and borehole type;
- Flow time: time for each data point given hourly in seconds (i.e. 3600 seconds for each data point); and
- Gas volume: amount of gas extracted for the data point (for the hour) given in litres.

An example of a .csv file is shown in Table 4. As noted in the table, the green highlighted text is the calculated flow for each data point. By dividing the gas volume by the flow time, as noted in Equation 2, the data provided gas volume as litres (L). This is ideal because it relieves the use of extensive decimal places if flows and flow rates were to be in cubic meters (m^3); Litres are a standard unit throughout the analysis process.

Table 4:
Maingate .csv data example

Log Time	Location	Sub Location	Well Name	Flow Time (s)	Gas Volume (L)	Gas Flow (L/s)
2/03/2017 9:00	Grasstree	German Creek	MG906_4	3600	3830758	1064
2/03/2017 10:00	Grasstree	German Creek	MG906_4	3600	3755053	1043
2/03/2017 11:00	Grasstree	German Creek	MG906_4	3600	3794622	1054
2/03/2017 12:00	Grasstree	German Creek	MG906_4	3600	3893576	1082
2/03/2017 13:00	Grasstree	German Creek	MG906_4	3600	3847571	1069
2/03/2017 14:00	Grasstree	German Creek	MG906_4	3600	3806197	1057

$$Gas\ Flow\ (L/s) = \frac{Gas\ Volume\ (L)}{Flow\ Time\ (s)} \tag{2}$$

Several inconsistencies with the data were noted throughout the analysis process. The major of these was the small values for the duration of maingate hole 1 (906MG-1) and no data recorded for maingate hole 2 (906MG-2). The duration for hole 1 was shorter and only ran for 39 hours, where others ran for weeks. The small values for 906MG-1 were in the range of between 1–5 L/s for the duration of the hole, which is comparatively lower than the flows seen in other holes that average around 1000 L/s. It was hypothesised that these flows were actually recording in m^3/s which would explain the difference of a factor of 1000 in the flows. This was discussed in a meeting with the industry supervisors and the conclusion was made that these were actually an issue with suction due to blockages within the borehole that resulted in 906MG-1 being shut down shortly after being brought online. The flows of 1–5 L/s were still put into the database.

The missing data for 906MG-2 was discussed, and as determined that the flow for this hole was not suitable; and, therefore, disregarded as 906MG-3 was pumped in its place. Table 5 provides the inconsistencies and the action taken upon discussion with industry supervisor.

Table 5:

Maingate flow inconsistencies

Maingate Hole	*Inconsistency*	*Date Range of Error*	*Action*
906MG-3	Low flow for several hours	Random instances	Left in database
906MG-4	Large block of low flow, 1–6L/s	9/03/2017 16:00–12/03/2-17 17:00	Left in database
	No data	7/03/2017 20:00	Averaged from data range above and fit if necessary
906MG-5	Low flow for the start of the borehole slowly increasing to approx. 1000 L/s after 1 day	Start of hole	Left in database
	No data	7/03/2017 20:00	Averaged from data range above and fit if necessary
906MG-6	Repeats data from hole 4 for part of the flow	Repeats until 14/03/2017 12:00	Removed repeating data and check dates of maingate hole start-up
906MG-7	Low flow 1-8 L/s	10/04/2017 13:00–10/04/2017 14:00	Left in database
906MG-8	Repeats data from hole 4 and hole 6 for part of the flow	Repeats until 27/03/2017 9:00	Removed repeating data and check dates of maingate hole start-up
	Low flow for the start of the borehole slowly increasing to approx. 1000 L/s after 4 day	27/03/2017 9:00–30/03/2017 6:00	Left in database
	No data	12/04/2017 19:00 and 12/04/2017 22:00–13/04/2017 0:00	Averaged from data range above and fit if necessary
906MG-9	Repeats data from hole 7 for part of the flow	Repeats until 11/04/2017 16:00	Removed repeating data and check dates of maingate hole start-up
	Flow lowers from 1000 L/s to 30 L/s	16/04/2017 0:00-25/04/2017 11:00	Left in database
906MG-10	Repeats data from hole 8 for part of the flow	Repeats until 16/04/2017 23:00	Removed repeating data and check dates of maingate hole start-up
	Low flow 1–8 L/s	1/05/2017 9:00 – 1/05/2017 15:00	Left in database
906MG-12	Repeats data from hole 10 for part of the flow	Repeats until 2/05/2017 18:00	Removed repeating data and check dates of maingate hole start-up
906MG-13	Repeats data from hole 11 for part of the flow	11/05/2017 4:00	Removed repeating data and check dates of maingate hole start-up
906MG-14	Break in flow between holes 12 and 13 to 14 and 15	21/05/2017 13:00–29/05/2017 10:00	Period of maingate roadway restriction no flows on maingate side of goaf

The majority of the minor inconsistencies involve the repeating of flow data for some boreholes. This is due to the reuse of the pumping systems on the surface where the data is collected and stored in the operating system. This was rectified by deleting the recurring data and analysing the dates to align each borehole to the correct start-up date. All maingate data provided was analysed and corrected, where needed, upon discussion with the industry supervisor.

4.3.3 Tailgate Drainage

The tailgate post–drainage holes at the Grasstree mine are vertical boreholes into the goaf area of the GC906 longwall panel. These boreholes were approximately 15” in diameter and spaced approximately 50m apart; 71 tailgate boreholes were drilled for the entirety of GC906. Surface drill rigs were used to drill and case the boreholes before measuring the flow once the hole was connected to the vacuum plant via overland pipe ranges. The tailgate drainage data was shared via the ‘Drop Box’, like the maingate data, as .csv files. The tailgate .csv files wells measured the flow rate rather than flow time and volume. An example of a tailgate .csv file is shown in Table 6.

Table 6:
Tailgate .csv data example

Log Time	*Longwall Name*	*Goaf Well Number*	*Goaf Well Name*	*Gas Flow Average (m^3/s)*	*Gas Flow Min (m^3/s)*	*Gas Flow Max (m^3/s)*
22/02/2017 0:00	LW906	34	GD906_34	1.453	1.445	1.459
22/02/2017 1:00	LW906	34	GD906_34	1.452	1.446	1.462
22/02/2017 2:00	LW906	34	GD906_34	1.452	1.444	1.459
22/02/2017 3:00	LW906	34	GD906_34	1.430	1.302	1.460
22/02/2017 4:00	LW906	34	GD906_34	1.299	1.288	1.316
22/02/2017 5:00	LW906	34	GD906_34	1.294	1.282	1.308

The gas flow rates provided gave the flow rate as cubic meters. This was multiplied by a factor of 1000 to obtain the flow rates as litres, Equation 3; this allowed consistency and relieves the use of decimal places. The same naming convention for maingate wells was also used for the tailgate wells; for example, tailgate well 1 was named 906TG-1. The tailgate flows had fewer data inconsistencies than the maingate wells, these are shown in Table 7.

$$Gas\ Flow\ (L/s) = \ Gas\ Flow\ (m^3/s) \times 1000\ (L/m^3) \quad (3)$$

Table 7:

Tailgate flow inconsistencies

Maingate Hole	***Inconsistency***	***Date Range of Error***	***Action***
906TG-40, 44, and 57	Low flows 1–15 L/s	Duration of the well	Left in database
906TG-42	Short well duration	13/03/2017 9:00–14/03/2017 17:00	Left in database may have been unstable well
	Low flow 1–15 L/s	Duration of the well	Left in database
906TG-58	Short well duration logged data of 0 for entire duration	Duration of the well 25/04/2017 14:00–27/04/2017 10:00	Left in database may have been unstable well

The inconsistencies for the tailgate wells were related to the low flows. This was hypothesised to be errors in the well-flow measurements because of the short durations of the well flows. However, upon discussion with the industry supervisor, it was decided that the flows were correct and to be left in the database. The flows which showed lower flows were blocked because of the movement in the subsurface and the smaller diameter of the boreholes which caused restrictions to the flow. Tailgate flows were put into the database on each of the corresponding timeline.

4.3.4 Underground Drainage

The underground post–drainage on site refers to the HGH boreholes located in 9 and 17 cut-through niches in the tailgate roadway. These niches are intersected during the longwall panel extraction. Therefore, drainage of the goaf via UIS drilling has a duration of approximately 2–5 weeks. During the extraction of GC906, HGH holes in 9CT and 17CT were flowing, 28/03/2017 0:00–27/04/2017 23:00 and 16/12/2016 5:00–1/01/2017 4:00 respectively. The naming convention for the two HGH boreholes was similar to that for the maingate and tailgate wells; for example HGH borehole in 9CT was named 906HGH-9CT. The files containing data for the HGH drainage were .csv format like those for the maingate and tailgate data. These files contained similar information to those of the tailgate flows where the flow rates were given in litres per second (L/s) at standard pressure, so there was no need for any conversions. However, the HGH flows were daily readings taken by a statutory officer. These recordings were tabulated and then sent to a .csv file to be stored for each hour of the day (i.e. one daily reading, was copied for each hour of the day).

Gas flow rates contained in the .csv file for 906HGH-17CT were all 0 data, where no flows recorded. It was hypothesised that the borehole was blocked due to movement in the rock around the boreholes in this cut-through. HGH drainage at 17CT was disregarded in the analysis process due to the data being incorrect. Therefore, the only HGH data to be used for the reporting of UIS post–drainage for GC906 is drainage from 9CT. Table 8 gives an example of the data contained in the 906HGH-9CT .csv file.

Table 8:

UIS HGH .csv data example

			Temperature °C	***Total Flow L/s at STP***	***Static Pressure kPa***	***Differential pressure Pa***
ON/OFF	***DATE***	***TIME***	***°C***	***L/s***	***kPa***	***Pa***
ON	28/03/2017	9:00:00	30.54	248	86.30	0.23
ON	29/03/2017	9:00:00	27.92	122	82.40	0.06
ON	30/03/2017	9:00:00	27.30	0	81.90	0.00
ON	31/03/2017	9:00:00	24.36	2	84.30	0.00
ON	1/04/2017	9:00:00	31.16	224	92.00	0.16
ON	2/04/2017	9:00:00	36.12	0	87.70	0.00

HGH drainage at 9CT extracted gas for approximately 1 month. The flow in 9CT started flow as a long range borehole at 28/03/2017 0:00 and flowed until the stand pipe was removed on 27/04/2017 0:00; because the longwall face reached the minimum safe operation distance from the 9CT niche where the borehole was located. The data for 906HGH-9CT was imported to the database created. This completed the raw drainage flows for the target analysis. Figure 12 presents the data for the total HGH flow rates over the hourly timeframe of the GC906 longwall panel.

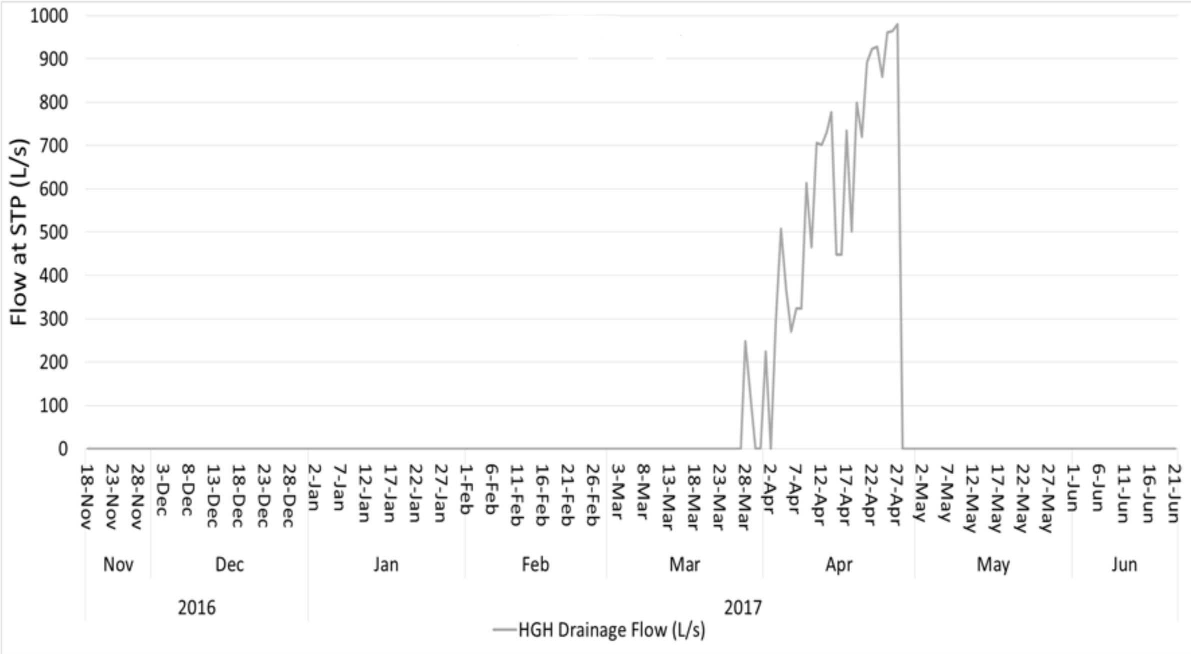

Figure 12: UIS HGH flow 9CT

9CT HGH flow is the entirety of the UIS post–drainage for the GC906 panel extraction. There is a general increase in flow rate as the duration of the hole increases. As the duration of the borehole extends, the closer the longwall face gets to the standpipe. The data was put into the database over the correct time frame for the GC906 longwall. These raw drainage inputs of maingate, tailgate, and HGH flows were checked by academic and industry supervisors.

4.3.5 Gas Plant and Blower Data

The gas plant and blower flare data were provided in .csv format. The gas plant data contains the flow at standard pressure and methane content of the extracted gas via the maingate and tailgate vertical goaf drainage holes and the horizontal UIS holes (906HGH-9CT). Unlike the previous raw drainage data, these files contained both the flow rate and gas content. The gas contents provided were the methane (CH_4) and carbon dioxide (CO_2) for each hour for the duration of the GC906 panel extraction. For this research project flow and methane content will be analysed. This was decided in the thesis application process. The vacuum gas plant data gave the total flow into the gas plant over the duration of the GC906, this is shown in Figure 13.

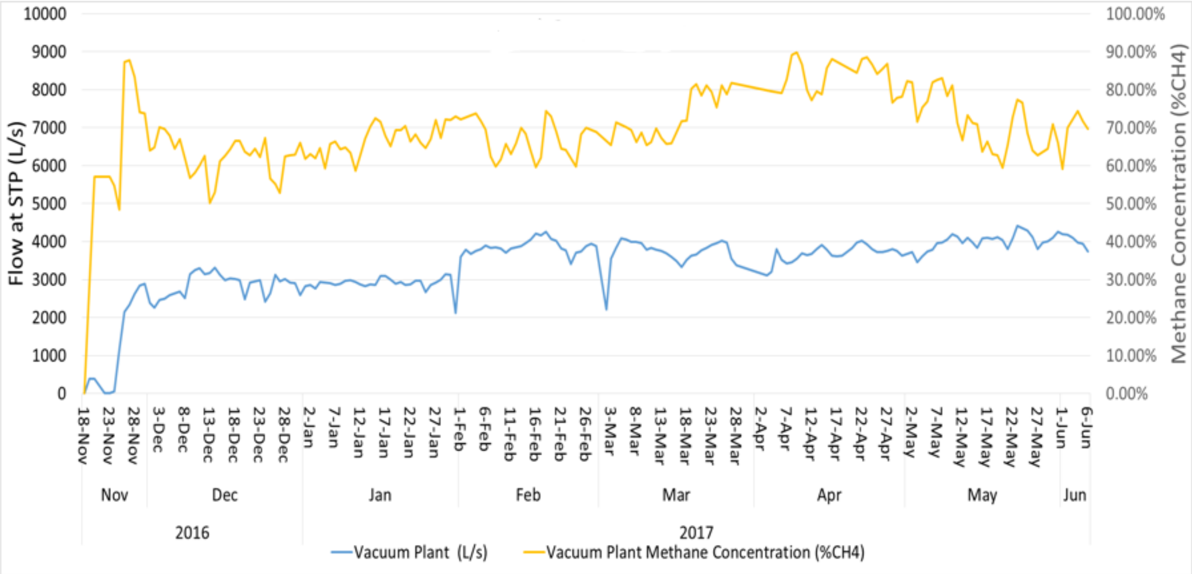

Figure 13: Gas plant flow and methane concentration

The gas plant methane concentration is the amount of methane within the flow into the gas plant. As noted, the methane concentration fluctuates. Although, once the GC906 longwall is fully running, the concentration stabilizes between 50–90%CH_4. The methane concentration increase between the start of March and end of April. Sharp declines presented in the gas plant flow were due to maintenance on the pipelines and gas plant shut downs, where the flows of 0L/s for several hours were averaged for the day. The gas plant data makes up part of the flow for the captured gas, the rest of the extracted gas was sent to the blowers to be flared off.

The four blower flares located at the site were used during the mining of GC906. The data files for the blowers were combined for all four blowers. The data contained the methane and carbon dioxide concentrations and the flows for each hour of the GC906 panel extraction. The flows for each blower and total blower flow are shown in Figure 14.

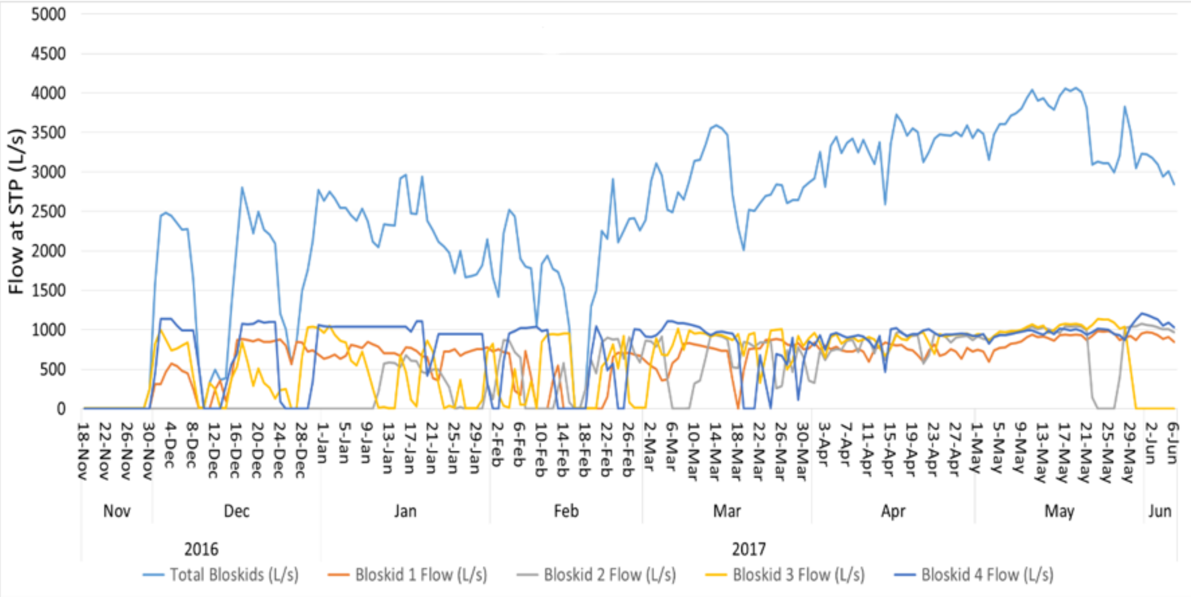

Figure 14: Total blower flow

The individual blowers were hard to examine due to flows being shut off. This was because the amount of extracted gas, once passed the gas plant for reuse is not enough to keep all flares going simultaneously. Therefore, some blowers were shut down. These are alternated to decrease the amount of ware on the flares. The total flow of the blowers were combined by adding all of the flows from blowers 1, 2, 3, and 4 for to create a single data point for each hour in the database. This allowed an accurate interpretation of the total blower flow and less chance of an error in calculations. Because the flows were combined, a weighted average of the methane concentration was required to allow an accurate measurement of the methane flared off. This was calculated using Equation 4.

$$Blower\ Methane\ Conc.(\%CH_4) = \frac{\sum_{i=1}^{4}(Blower\ Flow\ \times Methane\ Conc.)}{\sum_{i=1}^{4}(Blower\ Flow)} \tag{4}$$

The calculated total methane concentration of the blowers allowed the gas capture efficiency of the gas drainage system to be measured. Figure 15 shows the total methane concentration of the blowers and the total flow.

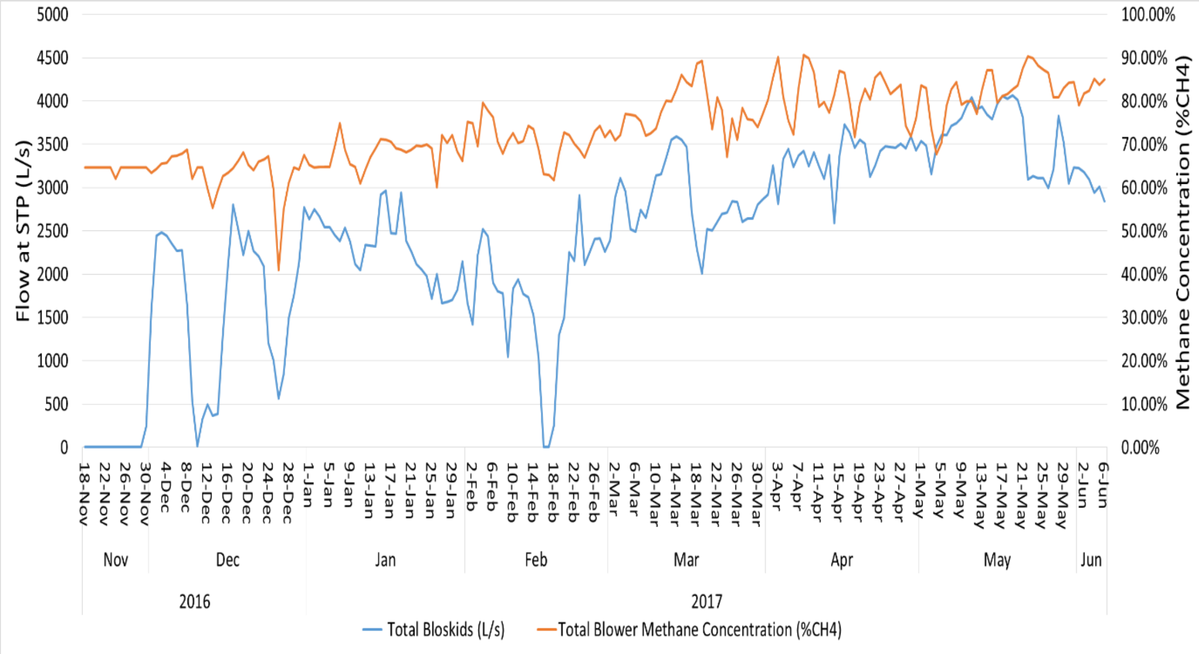

Figure 15: Total blower flow and methane concentration

There is a notable correlation between the methane concentration and the flow rate over the duration of the longwall panel extraction. It is also noted that there is an increase in the methane concentration over the GC906 extraction period. This was also noted in the Vacuum plant methane concentration. The increase in methane for the later part of the longwall extraction period occurs due to the increase in depth of the mining seam. The larger expanse of the goaf area as the longwall progresses, and the release of gas from adjacent seams as the goaf expands. These factors will influence the gas drainage of the entire system; and, therefore, will be taken into account for future work recommendations.

The captured gas for blowers and the gas plant were put into the database. The remaining gas within the ventilation system is part of the KPI for this research project. The ventilation system affects the work environment, production, and development of the mine, and gas within this system needs to be recognised and minimised wherever possible.

4.3.6 Ventilation Reports

Statutory ventilation reports are taken throughout the mine when a ventilation change has occurred. The readings for the GC906 panel were taken throughout the maingate roadways, several places across the longwall face, and throughout the tailgate roadway. The ventilation reading taken in the dogleg in the return roadway of the tailgate, as seen in Figure 11, is the total airflow which has travelled from the maingate and across the longwall face. The statutory ventilation reports are manually recorded after the ventilation change. The recorded data includes area information, changes to the ventilation, and airflow change from the previous report. Seven ventilation changes which altered the airflow in the GC906 dogleg during the report period. Figure 16 shows the recorded airflows for the duration of the panel.

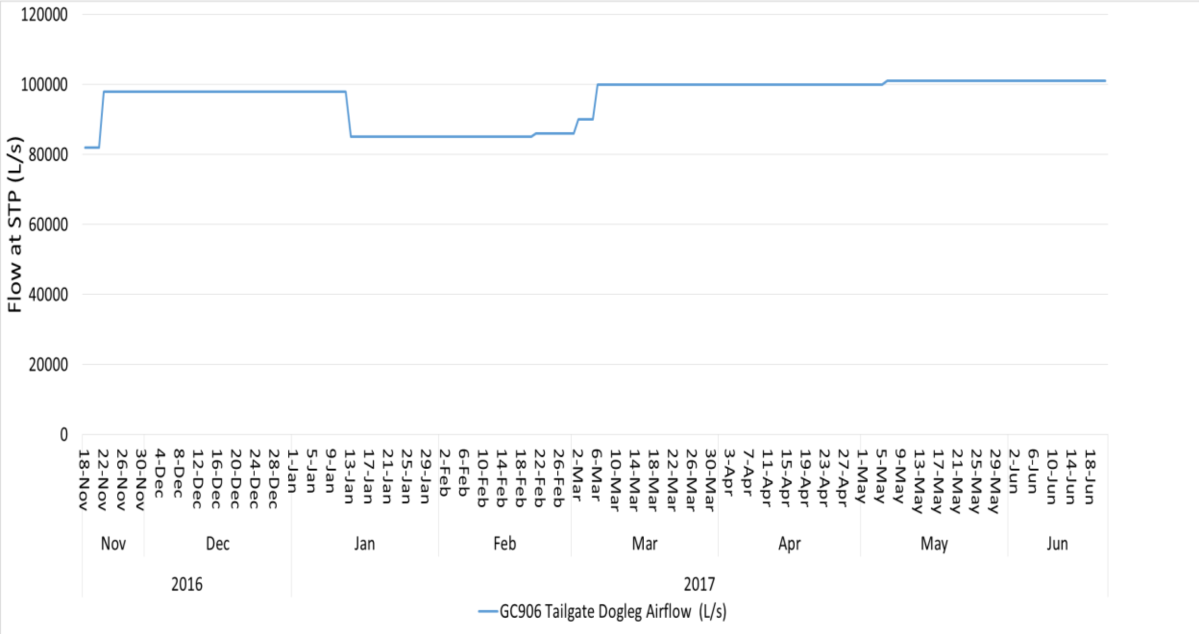

Figure 16: GC906 dogleg return airflow

The airflows from a ventilation change report through to the issue of a later report were copied as it was assumed that the airflow did not change until another report was issued. Approximately 100m^3/s of return air was recorded to be flowing through the panel, therefore with the planned ventilation of 50m^3/s for ongoing panels, this airflow will be halved. A separate .csv file was provided for the major gas concentrations in the return airway. These were recorded hourly to keep an accurate track of gas content in order to carry out TARPs if necessary. Gas concentrations provided were methane and carbon dioxide. Again for the purpose of this research project, methane will be analysed rather than carbon dioxide. Figure 17 presents the airflow and the methane concentrations in the GC906 dogleg return.

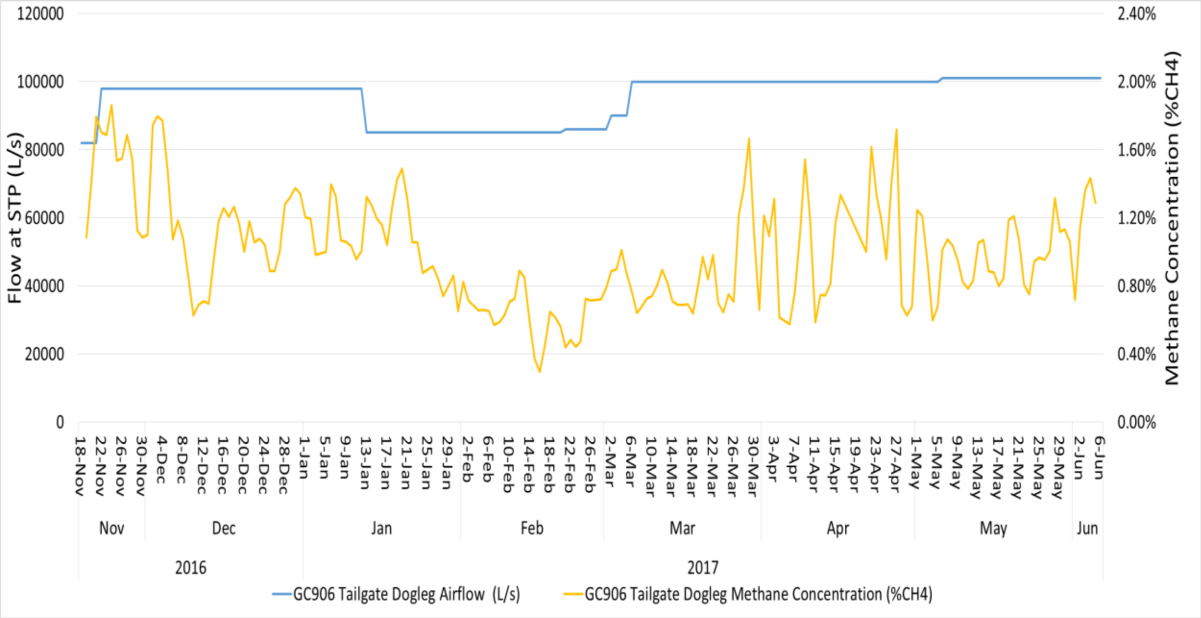

Figure 17: GC906 dogleg return methane concentration and airflow

The methane concentrations are noted to increase and decrease throughout the duration of mining. There is some correlation seen in the amount of methane in the airflow and the amount of airflow throughout the panel. With the ventilation planned to be limited in future panels, it will be of fundamental importance that the amount of gas remaining in the ventilation system be as low as possible. The GC906 return airflow and methane concentration was put into the database with the remainder of the data to begin the first stages of calculating the gas capture efficiency.

4.4 Methane Capture Efficiency

Before the gas capture efficiency was calculated, gas concentrations were required to be normalised. Normalising the gas concentrations for each data allows for the simple calculation of the capture efficiency. By identifying the gas make for both the total captured gas and the remaining gas in the return airflow, the capture efficiency could be calculated. The sum of the total flows (combined maingate, MG, tailgate, TG, and HGH flows) was calculated using Equation 5. All equations were calculated for the full duration of the GC906 panel. Figure 18 shows the total gas flow.

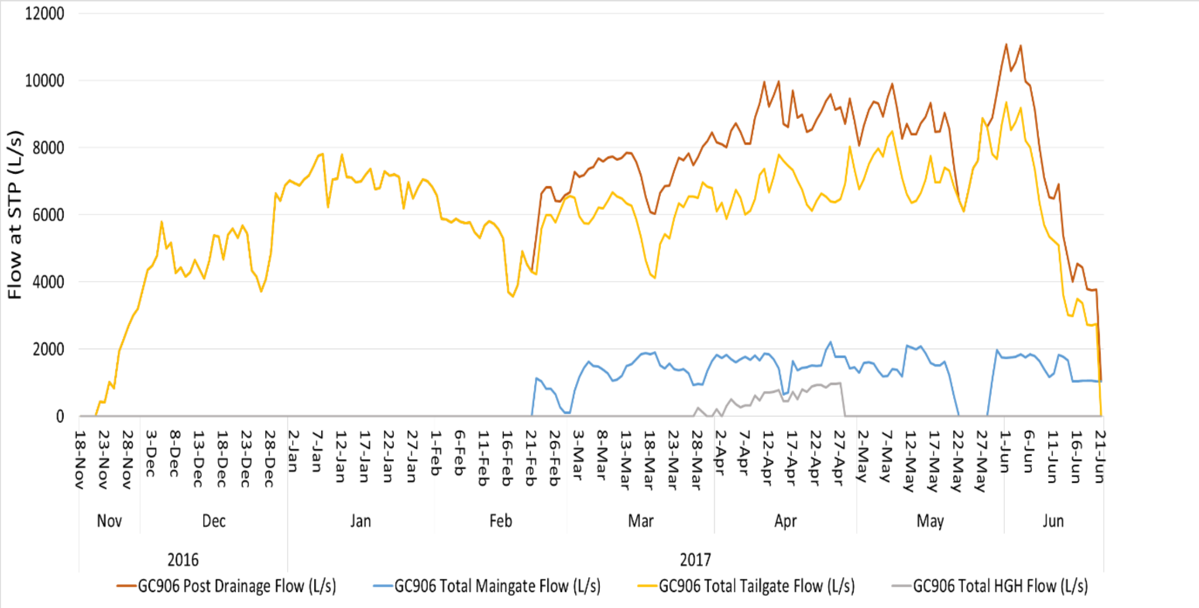

Figure 18: GC906 post – drainage flow

$$GC906\ Post - Drainage\ Flow\ (L/s) = \sum (MG\ Flow + TG\ Flow + HGH\ Flow) \quad (5)$$

The total post–drainage flow for the GC906 panel is heavily influenced by the vertical wells on the tailgate side. This is due to the closer spacing of the wells and therefore more wells actively flowing than on the maingate side at the same time. There was a notable correlation between the maingate and tailgate flow. This is particularly evident between the 22–27/05/2017 where the maingate flow stops, the tailgate flow also decreases. The maximum flow for the duration of the panel was 11 809L/s, which occurred on 1/06/2017 at 11:00am; while the average post drainage flow over the entire duration was 6708L/s. A weighted average of the total gas extracted from the mine was required to progress. This was calculated using Equation 6.

$$Captured\ CH_4\ (\%) = \frac{Blower\ (Flow\ \times\ CH_4\ Conc.) + Vacuum\ (Flow\ \times\ CH_4\ Conc.)}{Blower\ Flow + Vacuum\ Flow} \quad (6)$$

Once the amount of captured methane was calculated as percentages of the flow, the make of the gas was required to be calculated. The gas make provides the amount of gas captured and the amount of methane left in the ventilation system as an amount rather than a percentage or concertation. Equations 7 and 8 were used to calculate the captured and remaining (in ventilation system) methane make respectively. Figure 19 shows the amount of methane captured and the amount left in the ventilation system.

$$Captured\ CH_4(L/s\ ) = GC906\ Post - Drainage\ Flow\ \times\ Captured\ CH_4 \tag{7}$$

$$Remaining\ CH_4(L/s) = \ Dogleg\ Airflow\ \times\ Dogleg\ CH_4\ Conc. \tag{8}$$

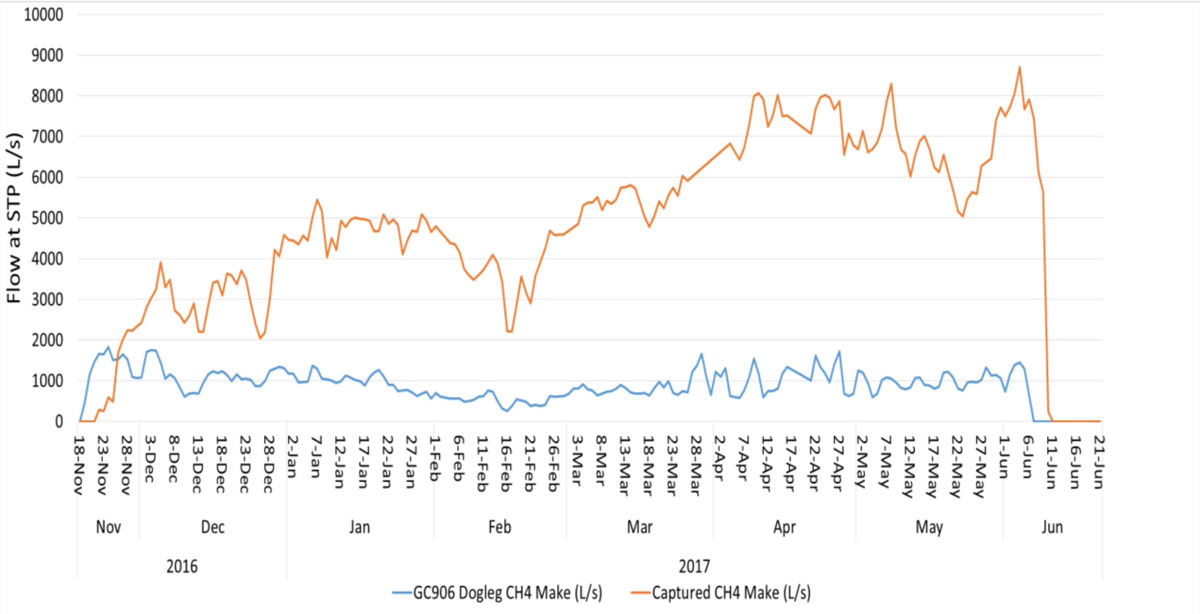

Figure 19: Captured and remaining methane make

The amount of methane captured per day increases as the mining continues; similar to the gas flow which increases with mining duration. The amount of methane in the return remained less than 2000L/s. The methane in the ventilation system fluctuates between mid–March and mid–April. These spikes in methane content may have caused brief slowdowns for equipment operating in the return roadways, as the increased methane content may have entered a higher TARP level. The methane capture efficiency was calculated using the equation from McPherson (1993) with inputs for this project; this is shown in Equation 9.

$$Methane\ Capture\ Efficiency\ (\%) = \frac{Captured\ CH_4}{Captured\ CH_4 + Remaining\ CH_4} \times 100\% \tag{9}$$

The methane capture efficiency is the performance indicator for scenarios in this research project. By identifying the capture efficiency of the gas drainage system in terms of methane for each hour of the longwall mining, changes during certain events can be recognised. Understanding these changes to the gas drainage system during events can better select which gas drainage strategies should be implemented for certain conditions.

Conditions and scenarios may vary between longwall panels. For longwall panel GC906, the main scenarios which were to be analysed were:

- Longwall square-up period;
- Two heading to three heading return;
- In-seam drainage;
- Roadway restrictions; and
- Maingate vertical post–drainage.

The aforementioned scenarios were selected by the Ventilation Compliance Superintendent to better understand what changes are seen in the methane capture efficiency and how this affects the gas drainage system. Each scenario was to be analysed, with changes in flow or capture efficiency noted and recorded.

5 SCENARIO ANALYSIS AND DISCUSSIONS

5.1 GAS DRAINAGE INFLUENCES

The gas drainage scenarios which are in scope, were selected as part of an investigation into the events that might affect the gas drainage system at Grasstree. Each scenario occurs throughout the duration of the GC906 panel extraction. Table 9 explains the scenario, when the scenario actually occurred (if any), and the date range which was analysed. The analysis range was picked to be approximately two-three weeks before and after the scenario occurred wherever possible, This allows any changes to be easily identified.

Table 9:

Scenario brief

Scenario	***Brief***	***Date***	***Analysis Range***
Longwall square-up period	Goaf area transitioned to rectangular goaf after the square-up period	7/12/2016	18/11/2016–28/12/2016
Two heading to three heading return	Tailgate return roadways transition from two gate roads to three gates roads	22/02/2017	1/02/2017–15/03/2017
In-seam drainage	Transition between long, short, and no UIS HGH in 9CT	-	Long Range: 2/04/2017–13/04/2017 Short Range: 14/04/2017–26/04/2017
Roadway restrictions	A restriction of B heading in the maingate cause airflow through only one heading	23/05/2017	16/05/2017–6/06/2017
Maingate vertical post–drainage	Changes in gas capture efficiency once the first post-drainage maingate vertical well hole starts	22/02/2017	1/02/2017–4/04/2017

5.1.1 Longwall Square-Up Period

The longwall square-up period is the transition of the goaf having a square ‘footprint’ and progressing to become a rectangular shaped goaf. This is a major geotechnical milestone, as the cavability of the roof in the goaf become apparent after this square-up period. At the Grasstree Mine, the GC906 longwall square-up period occurred when the goaf became 340m x 340m square. This occurred on 7/12/2016. Taking a period of three weeks before this date gives an analysis range of 16/11/2016–28/12/2016; however, the data provided begins on

18/11/2016. Instead of averaging data for two full days before the recording started, the start of the analysis will be on 18/11/2016 this will minimise the chance of incorrect data and errors.

To analyse the square-up scenario, the total post–drainage flow and the methane capture efficiency was analysed over the scenario period. Any changes to the gas drainage system was noted from the graphical analysis, recorded, and stated in the final conclusions. Figure 20 graphs the analysis of the GC906 square-up period.

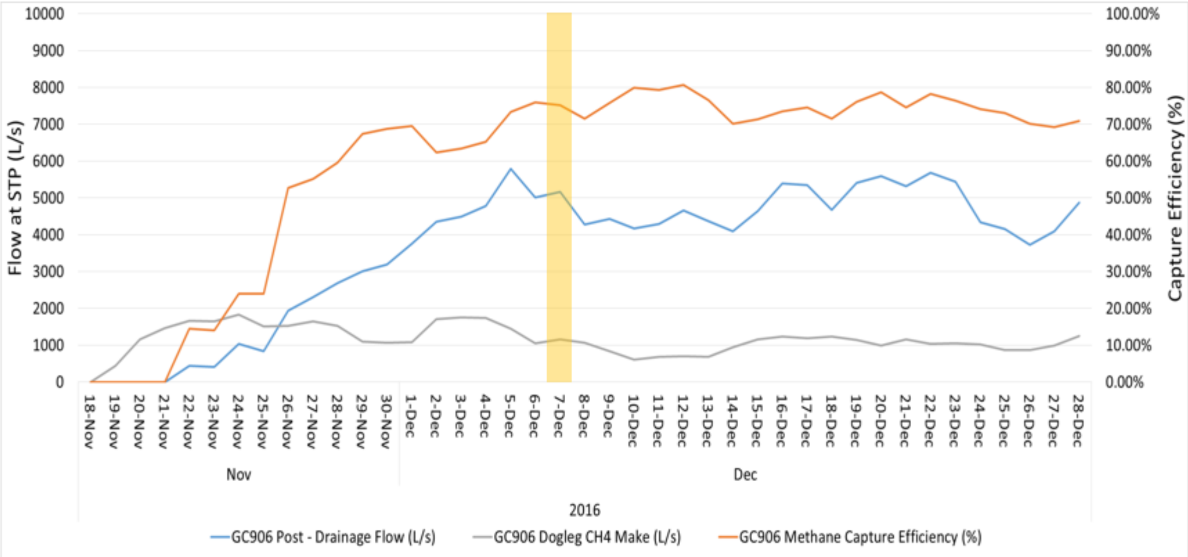

Figure 20: Longwall square-up period analysis

During the square-up period, only the post–drainage vertical holes on the tailgate side are active. There is a noticeable decrease in gas flow for the week following the square-up period, while there is an increase in methane capture efficiency for the same period. The methane capture efficiency over this period had a brief maximum of 81% on 12/12/2016 but had an average of 72%. This low methane capture efficiency would have a detrimental effect on the ventilation systems capacity for dilution. The methane make in the panel dogleg is approximately 1900L/s and the total airflow is approximately 100 000L/s. A high reading of methane, such as 1.9%CH_4, as seen during the square-up period is not ideal as there are vehicles and machinery experiencing slow work. Low capture efficiency puts a major strain on the ventilation system to dilute the gas with air. Having over a month with a low methane capture efficiency strains a ventilation system with approximately 100m^3/s of total airflow, for future blocks with 50m^3/s this would be unsuitable as the gas content is expected to increase slightly with depth. Therefore a major change is required to the gas drainage system at the beginning of the longwall panel to minimise the amount of gas in the ventilation system.

5.1.2 Two Heading to Three Heading Return

The two heading return roadway in the GC906 panel extends from the face start-up until the 19CT. From there, three roadways are used for the return air, as seen in Figure 21. The longwall face passed the GC906 tailgate 19CT on the 22/02/2016. Because of the limitations of ventilation in future longwall panels, fewer roadways will be developed to allow a suitable flow of ventilation to the face. A graphical analysis presented the effects of transitioning from two to three return roadways, in terms of gas capture efficiency and total flow.

Figure 21: GC906 Tailgate two to three heading transition at 19CT
(Anglo American Metallurgical Coal, 2017)

Figure 22 presents the methane capture efficiency and flows for the three week period before and after the return roadways transitioned from two to three. It was hypothesised that there would be minimal affects to the capture efficiency or flows because the goaf area is increasing at the same rate.

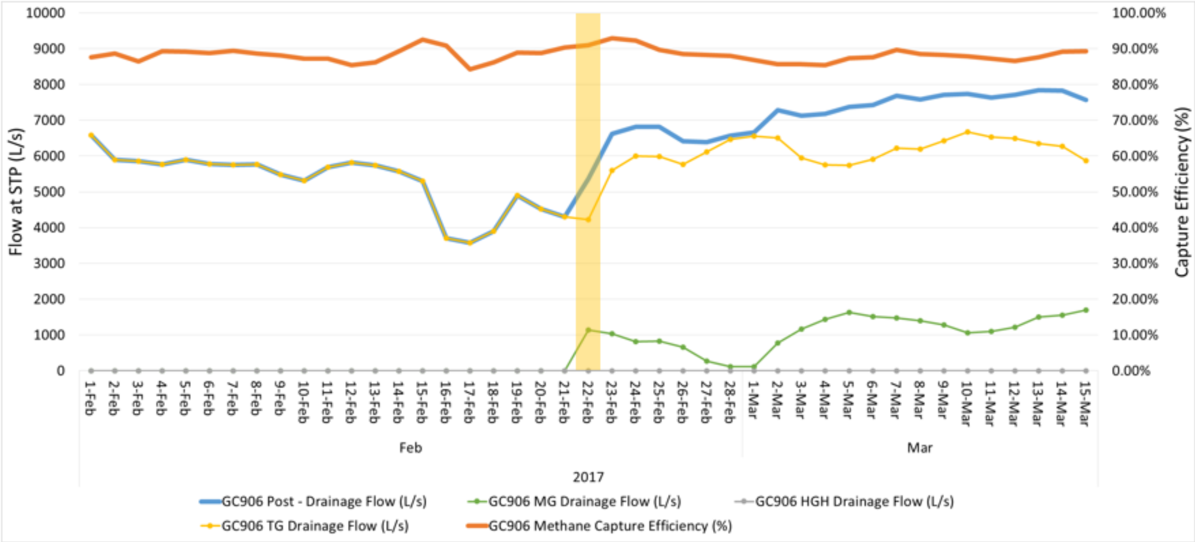

Figure 22: Two to three heading transition

On the 22/02/2017, when the longwall face passes the transition point of the two to three heading return roadways, the first of the vertical well flows occur on the maingate side of the goaf. This causes a sharp increase in the total gas drainage flow (in blue). However, the day after the transition, when the face and the goaf line has passed 19CT, there is an increase in the vertical post–drainage flow on the tailgate side. This increases the total tailgate flow from approximately 4500L/s to 5500L/s and further increases over the next week. This increase has no effect on the methane make in the dogleg, where the levels stay around 1000L/s. There are no HGH post–drainage flows active during this analysis period.

The methane capture efficiency decreases slightly by approximately 5% over the week period following the transition, however the total flow increases. The efficiency stabilises shortly after at approximately 90%, leaving 1000L/s of methane in the dogleg return. Leading up to the transition period, the capture efficiency appears to increase from 85% to 90% over a week long period.

There is no requirement to increase the size of the vertical wells during a three heading roadway scenario. However, the results found an increase is required for a two heading period to allow capture efficiency to stabilise at approximately 90%. This increase will reduce the strain on the ventilation system with a limited airflow.

5.1.3 In-Seam Drainage

In-seam drainage refers to the post–drainage efforts of the UIS HGH borehole in the tailgate. The borehole was drilled at the 9CT niche into the active goaf area. The borehole transitions from a ‘long hole’, where the standpipe is 550-300m away from the longwall face, to a ‘short hole’ where the standpipe is less than 300m away from the face. This transition is notable because the hole will experience changes in gas make, flow, and concentration depending on its position within the goaf area as it expands. The scenario takes into account a week before 906HGH-9CT hole, the long hole period, short hole period, and a week after HGH flow has ceased. This will provide an insight to how the gas flow is altered through the duration of the UIS hole, as well as how the capture efficiency and remaining gas make in the return is affected. Figure 23 presents a graphical analysis of the scenario.

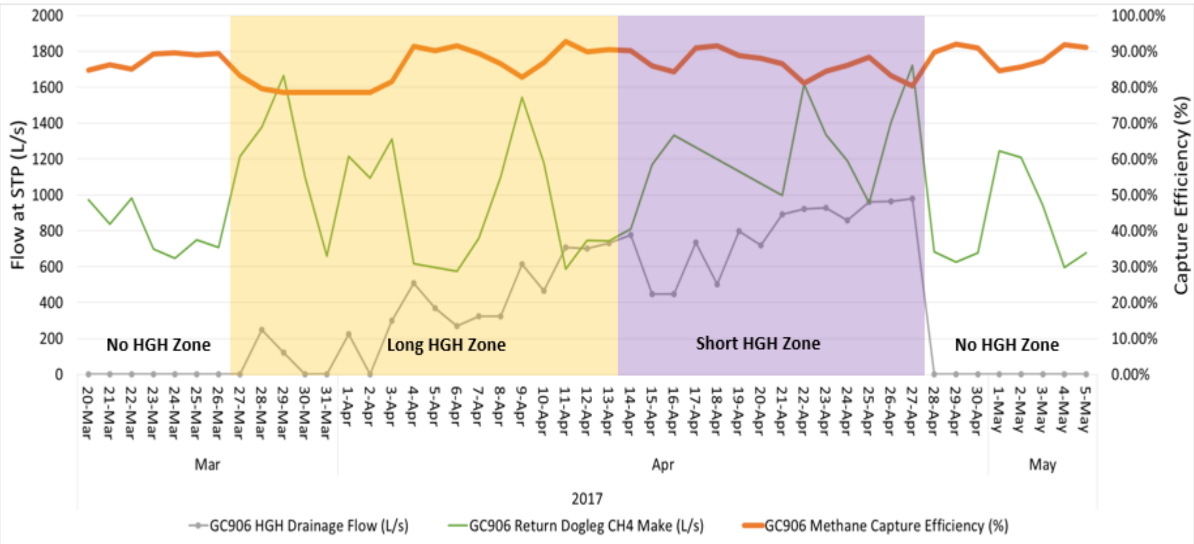

Figure 23: 906HGH-9CT in-seam transition

Most notable is the increase of HGH gas flow as the longwall face becomes closer to the 9CT niche. The maximum HGH flow occurs on 27/04/2017, when the flow was approximately 990L/s. This is a high flow for a UIS borehole of approximately 96mm in diameter. Another notable change over this period is the sharp decline in capture efficiency once the HGH borehole is brought online. The methane capture efficiency was approximately 90% the day before the HGH well began gas extraction. Once started, the methane capture declined to 80% efficiency. For the duration of the UIS gas extraction, the capture efficiency fluctuated in a weekly cycle averaging 94% efficiency.

From the analysis of one HGH well for the entire GC906, it was believed that UIS post–drainage is not efficient because of the decline in overall methane efficiency as soon as the HGH borehole began gas extraction. Because only one HGH well was able to be analysed, more studies are required to conclude that UIS post–drainage should be excluded from future gas drainage systems. In particular, more studies to determine the methane make from just the

HGH wells, would provide a more thorough opportunity to rate this gas drainage method against all others utilised on site.

5.1.4 Roadway Restriction

A roadway restriction was carried out in the B heading of the GC906 tailgate. The restriction was designed to better control the goaf dynamics in the tailgate corner. The restriction occurred on the 23/05/2017, an analysis of the two week period prior to the restriction and two week period after the restriction was undertaken. This gave enough time for any stabilisation to occur to the flows and efficiencies. Figure 24 provides the graphical analysis of the scenario for flow and methane capture efficiency.

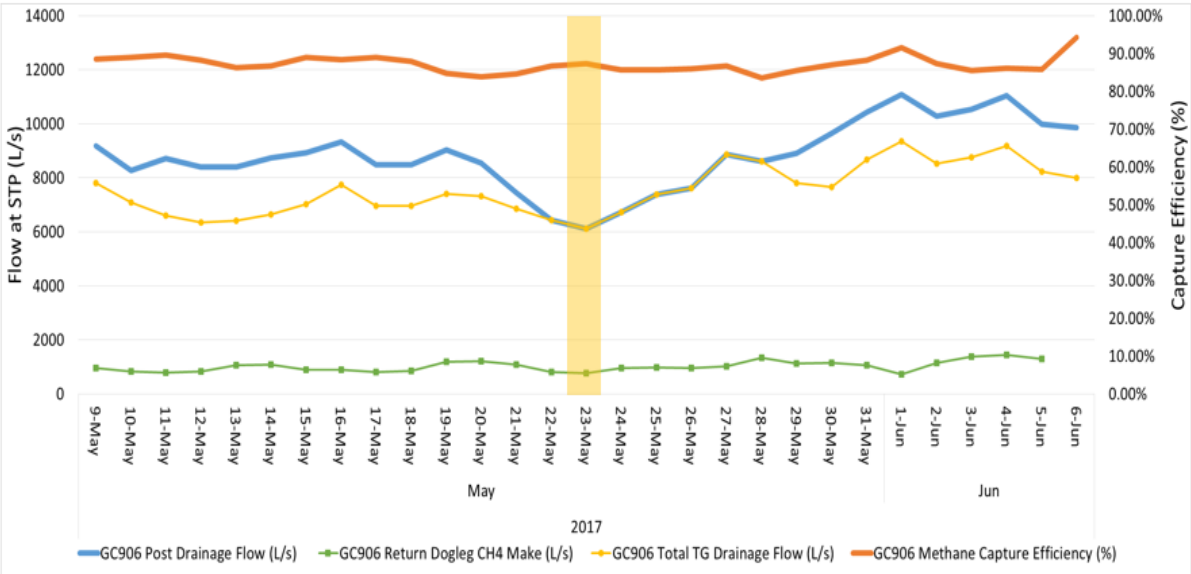

Figure 24: Tailgate roadway restriction analysis

From the graphical analysis, there is a definite decrease in post–drainage flow on the day the restriction occurred. This is because vertical post–drainage on the maingate side were shut down for a week from the 22/05/2017. This only left the tailgate side vertical wells to extract gas. However, from analysing the tailgate flows, there is a decrease up until the restriction, but, for a week period afterwards, the total tailgate well flow increase. These increases and decreases are better seen in Table 10, which gives a two week average before and after the restriction took place.

Table 10:
Tailgate roadway restriction analysis

	Average Before Restriction	*Average After Restriction*	*Difference*
GC906 Total Post–Drainage Flow	8457 L/s	9353 L/s	896 L/s (11% increase)
GC906 Methane Capture Efficiency	87 %	87 %	0% no change
GC906 Tailgate Gas Flow	6975 L/s	8243 L/s	1268 L/s (18% increase)
GC906 Dogleg Return Airflow	939 L/s	1135 L/s	196 L/s (21% increase)

It is clear to see from Table 10 that the restriction in B heading of the three heading return roadway had no effect on the methane capture efficiency. However increases to the tailgate gas extraction and overall gas extraction was noted. It was hypothesised that the methane make would not be affected, however the increase of 21% to 1135L/s is substantial. This methane make would be low enough to not cause harm. But with restricted ventilation to occur in future longwall blocks, the gas drainage system may have to be studied further to identify the cause of the increase.

5.1.5 Maingate Vertical Post-Drainage

Major increases to the total post–drainage flow occurs when the gas extraction on the vertical wells over the maingate side of the block begins. The analysis of the maingate wells was beneficial in determining if maingate holes are efficient in capturing methane. The analysis took place two weeks prior to the gas extraction from the first maingate hole and two weeks after two holes were operational. Figure 25 presents the time period of the analysis, total maingate and post–drainage flows, and the methane capture efficient for this scenario.

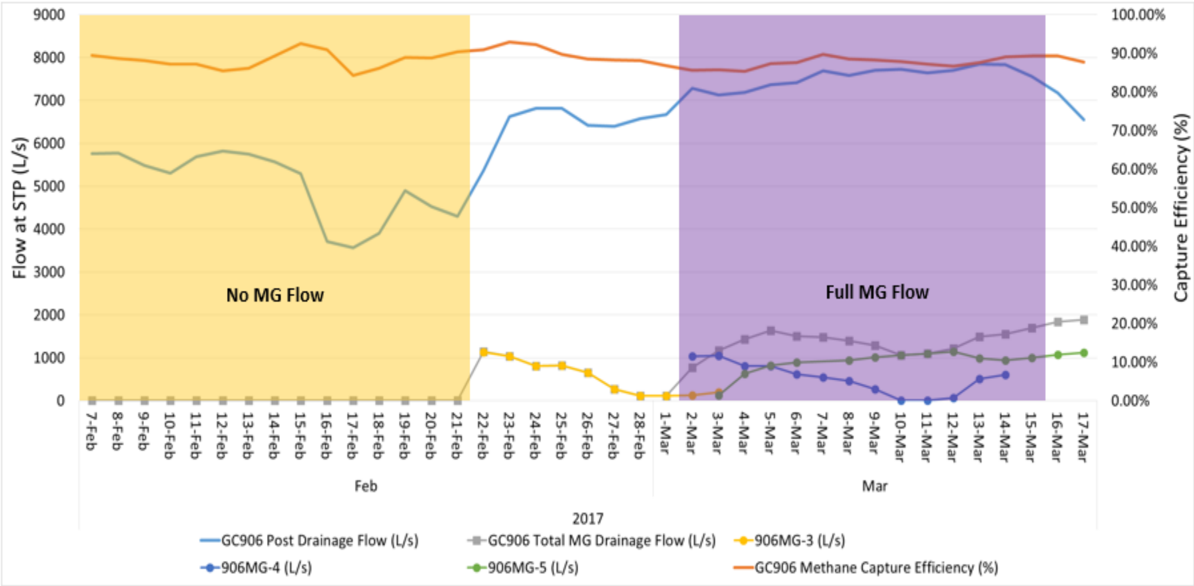

Figure 25: Maingate post-drainage analysis

The maingate post-drainage flow increases the total flow once gas extraction begins. For the two week period prior to maingate wells beginning extraction, the overall post–drainage flow (purely tailgate vertical) shows unstable behaviour; increases and decreases are notable. However, once extraction begins on the maingate side flow stabilised. The capture efficiency decrease. To get a better understanding, an average for the two weeks prior of maingate extraction and two week of full gas extraction was taken; this is presented in Table 11.

Table 11:

Maingate post–drainage analysis

	Average without MG Flow	***Average with Full MG Flow***	***Difference***
GC906 Total Post–Drainage Flow	5021 L/s	7547 L/s	2526 L/s (50% increase)
GC906 Methane Capture Efficiency	88 %	86 %	2% (2% decrease)

A 2% decrease in capture efficiency occurred when the maingate holes were fully functional and operating. But, the post–drainage flow of captured gas increased by 50% when the maingate holes were operational. For future longwall blocks, this 2% decrease in efficiency plus limited ventilation may cause a large strain on the ventilation system.

Further analysis of the next longwall block may be required, as the data 906MG-1 had a large amount of errors and 906MG-2 data was not recorded. An increase in total flow would occur if 906MG-1 and 2 were available, this would have resulted in altered methane capture compared to the initial analysis.

5.2 FURTHER DISCUSSION

The scenarios analysed were intended to measure performance one factor at a time, so that there was no other change in the analysis period for each scenario. However, some of the scenarios overlap time periods; therefore, they were not ‘stand-alone’ tests; other changes may have occurred in the gas drainage system. The timeframe for each scenario overlaid with the total methane capture efficiency of GC906 is presented in Figure 26

Figure 26: Scenario timeline

The Two Heading to Three Heading Return, In–Seam Drainage, and the Maingate Vertical Post–Drainage scenarios overlap periods. Therefore, when analysing one of these scenarios, changes have also occurred in another. This gives an incorrect analysis of any of the three overlapping scenarios. Therefore, an investigation for each of the three scenarios must be taken as ‘stand-alone’ tests where no overlapping changes can affect the data. Statements, discussions, and conclusions made for the Longwall Square–Up Period, and the Roadway Restriction can be used for the completion of this thesis. Recommendations have been made to improve future research studies in the gas drainage and ventilation field; Section 8.2.

6 PROJECT MANAGEMENT

6.1 SCHEDULE

Eleven primary tasks were scheduled to achieve overall completion of this undergraduate thesis, these are shown in Table 12. The thesis was conducted both semesters one and two in 2017, with the primary literature and data collection scheduled in semester one, data analysis throughout the June/July period, and writing of the examiner's copy in semester two

Table 12:
Project milestones

Task Name	***Duration***	***Start***	***Finish***
Supervisor Consultation	186 days	Tue 21/02/17	Tue 7/11/17
Submit Proposal to be Accepted into MINE4122	1 day	Wed 22/02/17	Wed 22/02/17
Project Proposal	7 days	Wed 22/02/17	Thu 2/03/17
Annotated Bibliography	7 days	Tue 4/04/17	Wed 12/04/17
Project Progress Report	15 days	Thu 27/04/17	Wed 17/05/17
Project Plan Agreement	1 day	Mon 29/05/17	Mon 29/05/17
Data Analysis and Discussion Notes	30 days	Thu 1/06/17	Sat 1/07/17
Conclusions and Recommendations	20 days	Sat 1/07/17	Thu 20/07/17
Seminar Presentation	36 days	Wed 2/08/17	Wed 20/09/17
Examiner's Copy of Thesis	78 days	Mon 26/06/17	Mon 9/10/17
Technical Conference Paper	7 days	Wed 18/10/17	Thu 26/10/17

The scheduled for this project is presented in Appendix B – Project Schedule, the duration of the project was 186 days. This was strictly adhered to allow minimal contingencies and failures, these are discussed in section 7.3.

Critical tasks for the minimal completion of this project are the data collection, analysis and summary of findings. These tasks all complete the aim of the thesis as a bare minimum. The critical path to the completion of the project is as follows:

- Data collection;
- Completion of progress report;
- Data analysis;
- Scenario discussion;
- Report findings back to industry supervisors;

- Completion of examiners copy of the thesis; and
- Completion of the final thesis through editing examiners copy.

All tasks were to be completed, however the above critical tasks created the basis of the project timeline.

6.2 BUDGET

6.2.1 Required Resources

Resources were required for the successful completion of the thesis project. The key resources include:

- Access to the data sources for collection and analysis;
- Appropriate software to view data and mine plans;
- Access to prior site-wide investigations related to the project; and
- Time allowed for discussions with industry supervisors

These key resources were planned into the timeframe of the project to allow the critical path to completion to flow smoothly.

6.2.2 Project Budget

Because all data was supplied and uploaded to a storage space for access, there was no cost incurred by either the mine site or the author. This allowed the project to be planned without financial liabilities. However, time costs have been included to show the cost of the project due to the time taken for academic and industry professionals to supervise this project; as seen in Table 13 The total project cost $14,150 due to the time taken for all involved.

Table 13:

Project cost

Expense	***Unit Cost ($/hour)***	***Time Input (hours)***	***Total Cost ($)***
Author	20	160	3,200
Academic Advisor 1	180	35	6,300
Academic Advisor 2	180	17.5	3,150
Industry Professional	180	8	1,440
TOTAL	-	**-**	**14,090**

6.3 RISK ASSESSMENT

Because the thesis project will be utilised for recommendations on an operating mine site, there is a need for contingency plans to alleviate the likelihood of reporting break downs. Several major hazards have the potential to jeopardise the project, without proper contingency plans in place the project would have been left vulnerable. The use of a risk assessment in a research project is to identify a hazard, quantify the risk and consequences, and plan a mitigation strategy to overcome major loss to the successful completion of the project. Table 14 provides the risk assessment for this project; Appendix C – Risk Assessment, presents the risk assessment matrix used to quantify the risks and consequences.

Table 14:

Risk matrix for the project

Hazard	***Initial Rating***			***Mitigation Strategy***	***Post Mitigation Rating***		
	L	***C***	***R***		***L***	***C***	***R***
Loss of communication with mine site No data provided No feedback returned Lack of interest from mine site	2	2	5 (L)	Convey early plans to communicate weekly and arrange times in advance for meetings Plan a ‘drop box’ or data storage devices available throughout the project Keep communication to site supervisor as discussed communicate with academic supervisor a contingency measure	1	2	3 (L)
Loss of data or report progress File corruption Non – submission of milestone tasks	3	4	18 (S)	Create stored backups o all files Save files correctly and store data storage safely Adhere to the planned project timeline to ensure academic milestones are completed	3	2	8 (M)
Change of project aim, objectives, data inclusions by mine site	2	4	14 (S)	Discuss all changes to be made with all supervisors as soon as possible to ensure that correct measures are taken in case of an objective change Identity which objectives have been changed or added and rectify within project progress report (if before due date for assessment) and make note in report	1	3	6 (M)

The major hazards which may cause an unsuccessful thesis report are as follows:

- Loss of data, files, or report;
- File corruption;
- Incorrect data;
- Inadequate timing; and
- Poor quality.

These hazards have the potential to fail the report and provide inaccurate recommendations to the mine site. The following contingency plans were put in place to mitigate these hazards.

- Saved all files and data in separate locations and updating whenever major milestones have passed allowing up to date copies if loss or file corruption occurs;
- Ensured that all data provide is reliable, and liaising with industry supervisor when the database was compiled;
- Adhered to the planned timeline of the project to ensure that all sub-reports and the final reports are completed to the best of ability; and
- Proofread all reports before submission, as well as following marking rubric throughout the report writing stages.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Gas management is a fundamental part of a safe ventilation system. Traditional methods of pre and post–drainage are widely used in the coal mining industry. Vertical and UIS post–drainage are the most common goaf gas drainage methods in Australia. Due to the increasing depth of coal seams, gas content of the seams are set to increase. Therefore gas capture efficiency must increase to avoid strains on the ventilation system which is used to dilute the uncaptured gas.

For future longwall blocks at the Grasstree Mine ventilation airflow is limited due to depth. Therefore gas management systems must be improved to maintain a safe work environment for mine workers. Strategic analysis of events which affected the gas management of the GC906 longwall panel were investigated as part of this project, these scenarios were:

- The longwall square-up period;
- Transition from two to three return airways in the tailgate;
- The duration of a HGH well transitioning from long to short goaf gas drainage;
- The restriction of a return roadway to improve goaf dynamics; and
- Analysis of the effects of vertical post-drainage holes over the maingate side on the overall gas drainage.

A database was created to calculate the methane capture efficiency for each hour of the duration of GC906 panel extraction. This allowed a detailed analysis of each scenario where airflow, gas concentrations, and capture efficiencies could be measured and compared. Each scenario was individually analysed to allow stand-alone changes to be discussed. However it was found that some analysis periods overlap, therefore alterations in capture efficiency and airflows could not be determined for individual scenarios. The overlapping scenarios were: Two Heading to Three Heading Return, In–Seam Drainage, and the Maingate Vertical Post–Drainage. Although, all scenarios were analysed, a few key findings were discovered.

During the transition period between two and three return headings, it was found that there was an increase in the post–drainage gas flow of approximately 1000L/s. This increase in gas flow did not correlate to methane capture, as there was no change before or after the transition period to the efficiency. This increase in flow may be linked to the amount of pre-drainage in chainage pillars on the tailgate side of the longwall panel, however further investigation would be required as this analysis was faltered due to the overlap.

For the analysis on the 906HGH-9CT well, it was determine that as the longwall face transitioned closer to the 9CT niche, therefore transitioning from a 'long' range to a 'short' range hole, the gas flow increased from approximately 400L/s to 600L/s respectively. During this analysis it was confirmed that the methane make recorded in the tailgate dogleg return experienced no unusual change and continued to fluctuate.

A major increase in total capture gas flow was noted during the analysis of the maingate vertical wells post–drainage. The analysis took a period two weeks prior to gas extraction on the mainagte side compared to when two wells were extracting. There was a 50% increase in total post – drainage flow once the maingate holes were extracting gas, as well as a 2% decrease in methane capture efficiency once the wells were operational. This decrease in capture efficiency may cause methane levels to increase in future panels with limited ventilation, therefore straining the ventilation system to dilute increased levels of gas.

The remaining scenarios were the Longwall Square–Up Period and the Roadway Restriction, these scenarios were both stand-alone tests where no other events took place. During the longwall analysis the methane capture efficiency, total post–drainage flow, and the methane make in the dogleg return were considered. The only gas extraction during this period came from the tailgate post–drainage wells. It was found that the capture efficiency averaged 71% for two weeks after the square–up period. This low capture efficiency caused a high amount of methane recorded in the dogleg return, approximately 1500L/s before the square–up and 1300L/s afterwards. A low capture efficiency causes a large strain on the ventilation system due to the gas dilution of 1.5–1.3%CH_4; the airflow was recoded to be approximately 100m^3/s (100 000L/s). It is recommended that mainagte vertical wells should begin extraction to increase the total extracted gas flow and improve the methane capture efficiency over this early period in the longwall extraction.

During the roadway restriction analysis of the total post–drainage flow, tailgate gas extraction, methane make in the dogleg return, and the methane capture efficiency was completed. The analysis period took the two week period prior to the restriction, and two week period after; roadway restriction occurred on the 23/05/2017. For the one week period directly after the restriction no maingate post-drainage flows were recorded. However there is a notable increase in the tailgate gas flow once the restriction was in place, the tailgate post-drainage gas flow increase by 18%. However the methane make in the return increased by 21% (to 1135L/s), there was no change to the methane capture efficiency which remained at 87% throughout the restriction timeframe. The methane make recorded was high, however, with reduced ventilation planned for future longwall panels, the methane make must not be allowed to increase by large amounts risking the safety and the production of the mine workers. Therefore, drainage over this period was inadequate.

In conclusion, this study enabled methane capture efficiency, as well as total and individual gas flows to the recorded and analysed against events which are known to impact the ventilation and gas drainage systems of underground coal mines. Some recommendations have been prepared for future longwall panels and gas management at the Grasstree Mine:

- Continue to utilise current gas drainage methods, however possible improvement to the measure of maingate post–drainage wells, the lack of recording of 906MG-1 and 2 may have made a difference to the results found during the longwall square–up period; and
- Improvements to the UIS goaf drainage HGH methods are required, although there were two cut-throughs which featured UIS post–drainage wells (9CT ad 17CT), more UIS goaf drainage may be required to allow gas extraction when vertical post-drainage wells are shut down for maintenance or other reasons.

7.2 RECOMMENDATIONS

Further recommendations following this research study would include both a wider scope and more detailed testing of issues which were found during the scenario analysis. These further recommendations will allow more literature in the field of gas drainage in Australian coal mines and more in depth study into the fundamental events which alter normal drainage techniques. The following are key recommended studies to be undertaken in the future:

- Determining the pre-drainage efficiency of the mine to determine where improvements can be made prior to mining the longwall panel, this will have lasting effects on the post–drainage efficiencies.
- Complete the same study for the other harmful gasses found in the mine ventilation, including carbon dioxide and carbon monoxide. This will allow a better understanding of the drainage system and how other mine gasses are extracted in the goaf area.

- Identifying the scenarios which were not stand-alone tests, a study where the events can be identified clearly, allowing a definitive set of conclusions for all scenarios. However, even with these events conclusions were made for flows with may be altered due to the scenario; for example the transition from two to three tailgate return roadways indicated an large increase in tailgate post–drainage flow.

These few recommendations would allow further depth to the gas drainage and ventilation field in underground coal mining, as well as allow experience for students in technical mining practices.

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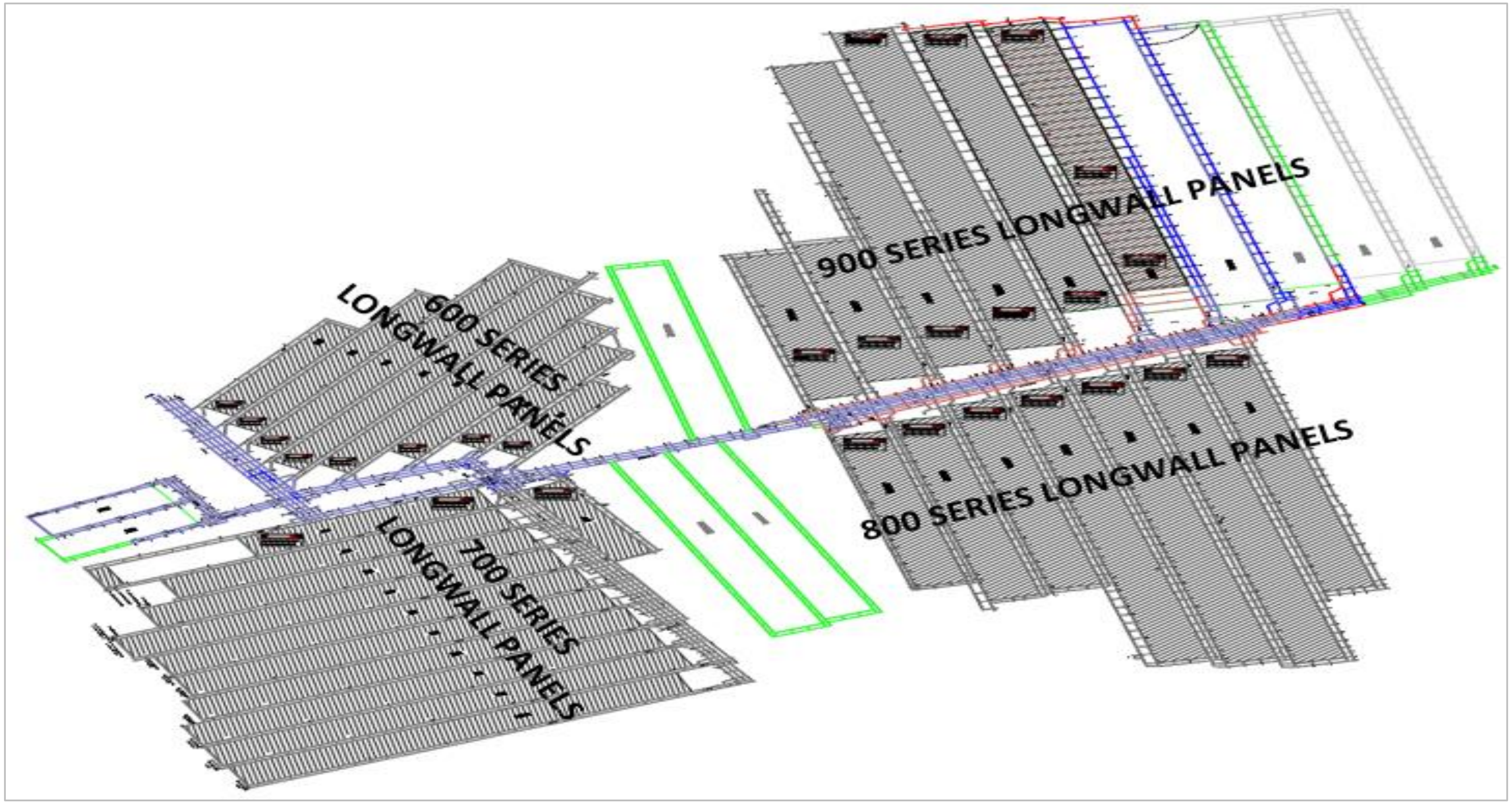
9 APPENDICES

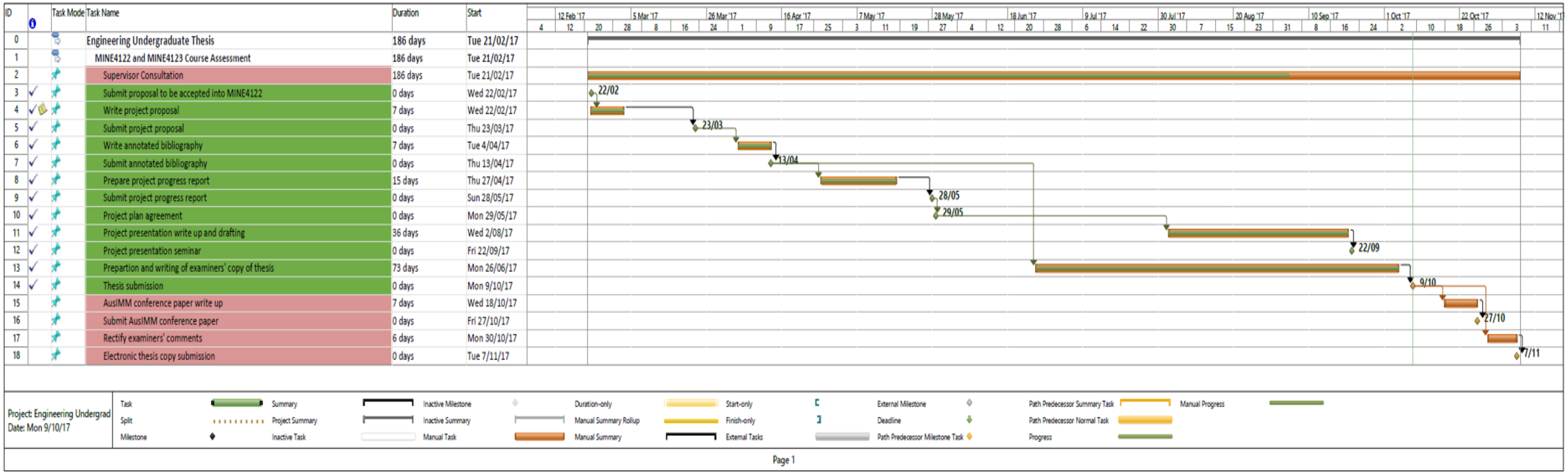
APPENDIX A – SITE PLAN

The updated site plan for Grasstree Mine, May 2017.



APPENDIX B – PROJECT SCHEDULE

The project schedule for this undergraduate thesis.



APPENDIX C – RISK ASSESSMENT

The risk assessment matrix used to quantify the hazards associated with this thesis.

Risk assessment matrix (Anglo American Metallurgical Coal, 2016)

	Consequence				
Likelihood	*Insignificant (1)*	*Minor (2)*	*Moderate (3)*	*Major (4)*	*Failure (5)*
Almost Certain (5)	11 (M)	16 (S)	20 (S)	23 (H)	25 (H)
Likely (4)	7 (M)	12 (M)	17 (S)	21 (H)	24 (H)
Possible (3)	4 (L)	8 (M)	13 (S)	18 (S)	22 (H)
Unlikely (2)	2 (L)	5 (L)	9 (M)	14 (S)	19 (S)
Rare (1)	1 (L)	3 (L)	6 (M)	10 (M)	15 (S)